RI 9069

PLEASE DO NOT REMOVE FROM LIBRARY

RI 9069

Bureau of Mines Report of Investigations/1987

Fugitive Dust Control for Haulage Roads and Tailing Basins

By Keith S. Olson and David L. Veith

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 9069

Fugitive Dust Control for Haulage Roads and Tailing Basins

By Keith S. Olson and David L. Veith

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Olson, Keith S.
Fugitive dust control for haulage roads and tailing basins.

(Report of investigations/United States Department of the Interior, Bureau of Mines ; 9069)

Bibliography: p. 31-32.

Supt. of Docs. no.: I 28.23: 9069.

1. Mining industries–United States–Dust control. 2. Mine haulage. 3. Spoil banks. I. Veith, David L. II. Title. III. Series: Report of investigations (United States. Bureau of Mines) ; 9069.

TN23.U43 [TN312] 622 s [620'.49] 86-600244

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

TABLES--Continued

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	lb/acre	pound per acre
dyn/cm	dyne per centimeter	m	meter
°F	degree Fahrenheit	m^2	square meter
ft	foot	mg/m^3	milligram per cubic meter
gal	gallon	mi/h	mile per hour
gal/acre	gallon per acre	min	minute
gal/min	gallon per minute	µm	micrometer
gal/yd^2	gallon per square yard	pct	percent
g/cm^3	gram per cubic centimeter	psi	pound per square inch
$g/(min \cdot m^2)$	gram per minute per square meter	psig	pound per square inch, gauge
h	hour	$/acre	dollar per acre
hp	horsepower	$/gal	dollar per gallon
in	inch	$/mi	dollar per mile
in/d	inch per day	s	second
kg	kilogram	st	short ton, 2,000 lb
kg/acre	kilogram per acre	yd^3	cubic yard

FUGITIVE DUST CONTROL FOR HAULAGE ROADS AND TAILING BASINS

By Keith S. Olson[1] and David L. Veith[2]

ABSTRACT

During 1982 and 1983, the Bureau of Mines concentrated its fugitive dust control research on haulage road dust suppression by newer chemicals relatively unknown in the mineral industry, innovative dust control designs for haulage trucks, chemical tailing basin stabilization, and combined chemical and vegetation tailing basin stabilization. Relatively unknown dust suppression chemicals and innovative aerodynamic modifications to haulage truck fender designs were tested on a Minnesota sand and gravel operation haulage road. Magnesium chloride salt at 95-pct control efficiency and a petroleum derivative at 70-pct control efficiency were effective in suppressing dust generated by haulage vehicles; however, none of the fender modifications were successful.

Commonly used dust suppressant chemicals were tested on a Minnesota taconite tailing basin to reduce the dust lift-off during the spring and fall dry seasons. The most successful chemical was lignin sulfonate with a seasonal cost of less than $200 per acre to achieve 90-pct dust control. When chemical treatments for immediate dust control were combined with revegetation for permanent control, the most promising chemical treatment based on vegetation response was lime-neutralized lignin sulfonate.

[1]Program analyst.
[2]Mining engineer.
Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

INTRODUCTION

Fugitive dust is an operational and environmental problem at most surface mines. Particulate emissions at surface mines are classified as fugitive dust because they mainly result from machinery movement, wind action, and material transfer at or near ground level. Discharges from stacks, flues, or ducts are not classified as fugitive dust.

Fugitive dust may be further described by the following definition from 40 CFR 52.21(b)(6):

> Particulate matter composed of soil which is uncontaminated by pollutants resulting from industrial activity. Fugitive dust may include emissions from haulage roads, wind erosion of exposed soil surfaces, and soil storage piles and other activities in which soil is either removed, stored, transported, or redistributed.

Fugitive dust includes any size dust particle that becomes airborne. Operational problems caused by excessive levels of fugitive dust at most surface mines include (1) reduced visibility near moving equipment, (2) excessive wear on engines, bearings, and other moving parts, (3) high maintenance costs due to more frequent oil changes and filter replacements, (4) decreased production due to reduced haulage truck speed caused by limited visibility (note that adding more trucks to increase production is costly, increases dust levels, and requires a further speed reduction), (5) excessive fines on unconsolidated road surfaces, which increases tire penetration and raises fuel costs, (6) unpleasant or possibly unhealthy conditions for employees, and (7) damage to plants on newly reclaimed areas. Environmental problems resulting from fugitive dust include complaints from neighbors and difficulty in complying with air quality standards.

The Federal primary and secondary ambient air quality standards for total suspended particulates (TSP) are contained in 40 CFR 50.6 and 50.7. It was the intent of this project to effectively reduce dust emissions from haulage roads and tailing basins.

Fugitive dust sources in surface mines include haulage roads, tailing basins, stockpiles, topsoil removal, drilling, blasting, overburden handling, mineral extraction, truck and rail car loading and unloading, material handling, maintenance and construction activities, and mineral processing. Since haulage roads and tailing basins are the leading sources of fugitive dust from surface mining operations (1-2),[3] the Bureau of Mines has directed the major part of its fugitive dust research to these areas.

Dust control from haulage roads and tailing basins has not been developed to the same extent as dust control from most industrial sources. The technology for controlling dust from industrial sources with conventional dust collectors is well documented, and continuous control or removal efficiencies may exceed 99 pct (3). These collectors include cyclones, scrubbers, fabric filters, and electrostatic precipitators. Such control is not possible for fugitive dust from haulage roads, tailing basins, or other open sources owing to the large unconfined areas involved, constant exposure to wind and weather, action of large trucks and other types of equipment, and dry surface conditions. Dust may be controlled effectively for several hours to several months by chemicals and/or water, but a long-lasting cost-effective control method is still needed.

Fugitive dust is controlled by containment, suppression, and removal. The research efforts described in this report include several types of chemical dust suppression and one containment measure. Application of water is the most popular method used to control dust at surface mines, particularly on haulage roads. Water is often not long-lasting, nor is it the most cost-effective type of control (4) because its relatively high

---

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

surface tension (72 dyn/cm) makes it a poor wetting agent for certain types of materials. Chemicals have been developed to provide more efficient control (4). Some are applied dry or as full-strength solutions, but most are mixed with water and applied as diluted solutions.

ACKNOWLEDGMENTS

The authors appreciate the cooperation afforded them by J. L. Shiely Co., the National Steel Pellet Co., and National's operating agent, the M. A. Hanna Co., for providing the test facilities and many other courtesies during the testing periods.

OBJECTIVE AND APPROACH

The objective of the Bureau fugitive dust research program was to develop technology to reduce dust emissions from haulage roads and tailing basins, so as to reduce costs, increase productivity, and protect the local environment. The Bureau work in road dust control during fiscal years 1982 and 1983 consisted of field testing "newer" chemical dust suppressants, for which little was known concerning their effectiveness (as contrasted with the well-known chemicals calcium chloride, lignin sulfonate, and Coherex[4]), and of devising innovative dust controls for haulage trucks. The initial approach to tailing basin dust control research was stabilization of the tailing surface with chemical dust suppressants. The next step consisted of combining the chemical treatment with seeding grasses and legumes to establish a more permanent type of dust control.

HAULAGE ROAD DUST CONTROL

The haulage road dust control research was performed at the J. L. Shiely Co. sand and gravel operation on Grey Cloud Island, Washington County, MN. The company is a major producer of sand and gravel and other aggregates for the Minneapolis-St. Paul metropolitan area. At this site, sand and gravel were mined by power shovel and backhoe and hauled to the plant by four bottom-dump trucks of 80- to 90-st capacity (fig. 1). The distance from the face of the pit to the plant was approximately 1 mile. The haulage route varied according to pit operations, but generally one road was used for hauling material to the plant, and another road was used for empty trucks returning to the pit. Both roads joined about 0.125 mile from the plant (fig. 2), and a round trip between the pit and the plant took about 20 min.

The company was interested in improving dust control from operational and environmental standpoints. Shiely used water application to control road dust levels, and during hot weather up to 50,000 gal of water per day was required to maintain proper control.

The company markets a variety of sand and gravel products which are mainly transported to distribution points by river barge. The remainder is hauled from the plant by truck. The haulage roads were constructed of local soil, which is quite sandy, with a top dressing of sand and gravel.

CHEMICAL DUST SUPPRESSION

Chemicals Selected for Testing

Four chemical dust suppressants were selected for testing: (1) AMS 2200, a petroleum derivative, (2) Dustgard, an $MgCl_2$ salt, (3) Dust-set, a resin, and (4) Haulage Road Dust Control, a wetting agent. These chemicals were selected for their differing characteristics and

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

FIGURE 1.—Loaded haulage truck traveling from pit to plant.

because not much was known about their effectiveness in suppressing dust. The most commonly used chemicals such as Coherex, lignin sulfonate, and $CaCl_2$ were not tested. The $MgCl_2$ salt was chosen because it was used in Bureau-sponsored contract research for tailing basin dust control (5), and its effectiveness in that study could be compared with that in this research.

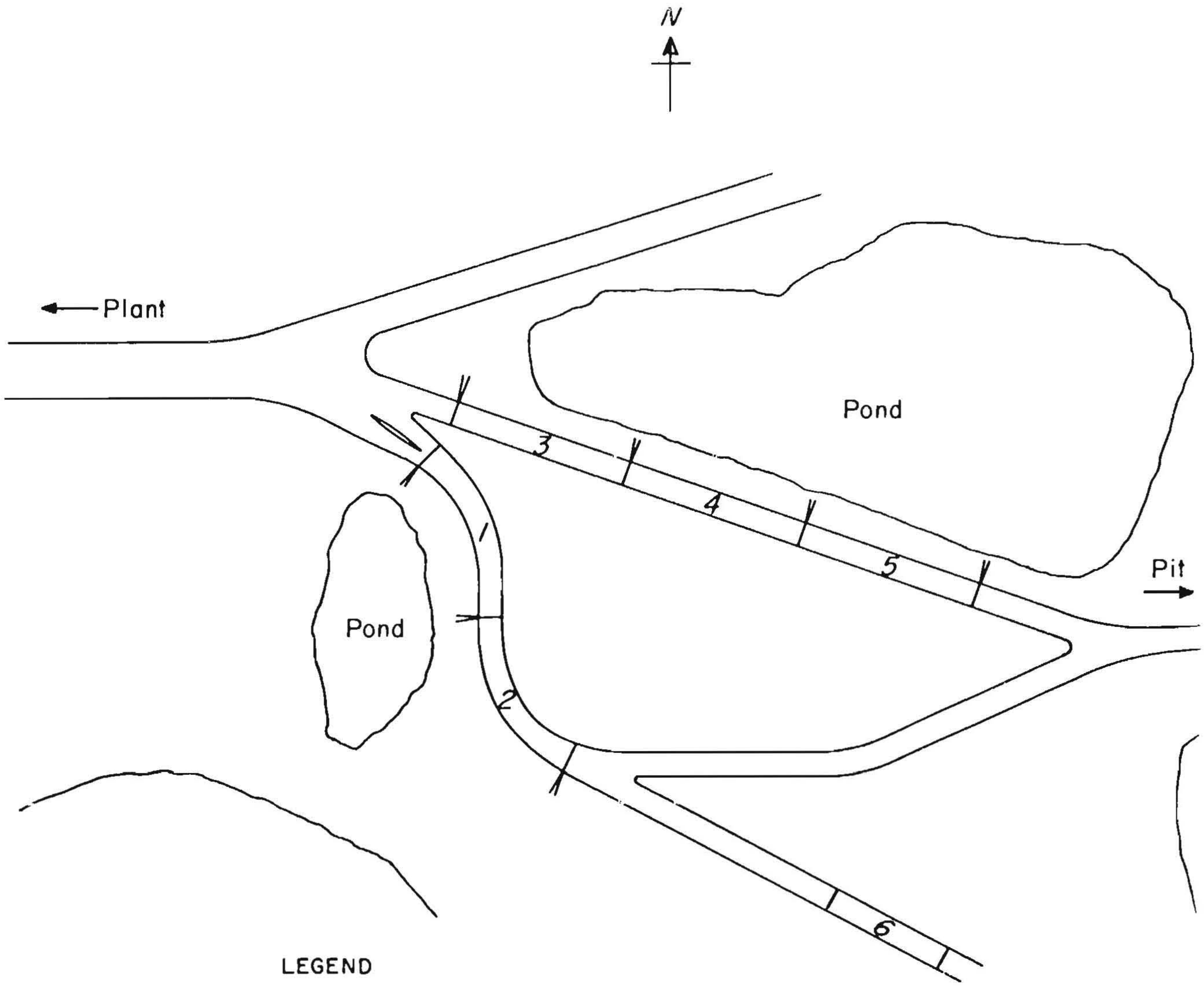
The petroleum derivative and resin control dust by binding the loose particles on the road surface into a crust to prevent the fines from becoming airborne. The $MgCl_2$ salt is hygroscopic and deliquescent, that is, the chemical absorbs moisture from the atmosphere and maintains the road in a moist condition to control dust.

Wetting agents used for haulage road dust control are applied as diluted solutions (e.g., 3,000:1). They are intended to improve the dust-suppressing capability of the water applied to the road surface by reducing the surface tension of water and increasing its wetting ability. The chemical and physical properties of the dust suppressants used in the Bureau's haulage road dust control are presented in table 1.

Surface Preparation and Chemical Application

The chemicals were applied to haulage road sections approximately 400 ft by 45 ft, as instructed by their respective vendors. The chemical application was made directly to the surface with no mixing or blading during or after application. A 400-ft-long untreated test area was located adjacent to the treated area, for comparison. These sections were also unwatered prior to testing the petroleum derivative, $MgCl_2$ salt, and resin.

The petroleum derivative test area required no pretreatment other than normal grading. Truck traffic provided enough compaction. The $MgCl_2$ salt required a moist surface to allow the chemical to penetrate (5); sometimes it may be necessary to apply additional water to provide that moisture. In the Bureau studies, a light rain falling during the first application of the $MgCl_2$ salt provided sufficient moisture, and the second



LEGEND

Area	Chemical	Application date
1	Petroleum derivative	August 1982
2	$MgCl_2$ salt	August 1982
3	$MgCl_2$ salt	October 1982
3	Resin	July 1983
4	Petroleum derivative	October 1982
4	Untreated control section	–
4	Wetting agent	July 1983
4	Water	July-August 1983
5	Untreated control section	–
5	Water	July 1983
5	Wetting agent	July-August 1983
6	Untreated control section	–

Notes:

a No emission testing from areas 1, 2 and 6 (see text)

b All areas are 400 by 40-45 ft

c Not to scale

FIGURE 2.—Map of the haulage road dust control test site.

TABLE 1. - Chemical and physical properties of dust suppressant chemicals used in haulage road dust control research

Dust suppressant chemical	Trade name	Color	pH	Sp gr, g/cm^3	Flash-point, °C	Boiling point, °C	Generic description
Petroleum derivative.	AMS-2200......	Tan....	7.0	0.98	>104	100	Aromatic petroleum-fatty acid emulsion.
$MgCl_2$ salt....	Dustgard......	Clear..	7.0	1.32	None	100	32 pct $MgCl_2$.
Pretreatment chemical for resin application.	Dust-Set-Amended Water Base.	..do...	5.5	1.09	77- 82	77	A blend of Dust-Set, sodium d-octyl sulfosuccinate, water, and ethanol.
Resin.........	Dust-Set Dust Abator.	..do...	4.5	1.05	None	100	Nonpetroleum cold water suspension of synthetic resins and adherents.
Wetting agent.	Haul Road Dust Control.	Pink...	7.2	NA	>260	NA	A blend of anionic and nonionic surfactants.

NA Not available.

TABLE 2. - Dilution and application rates for dust suppressant chemicals used in haulage road dust control studies

Dust suppressant chemical	Dilution ratio, water:chemical	Application rate, gal/yd^2	
		Solution	Chemical
Petroleum derivative.	4:1	1.0	0.2
$MgCl_2$ salt.....	None	.5	.5
Resin:			
Pretreatment.	100:1	.25	<.005
Resin........	24:1	[1].25	.01
Wetting agent	3,000:1	[2].15- .20	<.005

[1]3 applications of resin were required.
[2]The wetting agent was applied prior to testing each day.

application was done after blading, which brought moist material to the surface.

The area treated with the resin was first sprayed with a conditioning agent (containing Dust-Set-Amended Water Base) to provide faster surface wetting and allow penetration from the surface. This pretreatment also prevented reactions between the resin and any hydrocarbons present in the roadway. No pretreatment was needed for the wetting agent.

The chemical dilution and application rates are given in table 2. All chemicals except the $MgCl_2$ salt were applied by Bureau personnel using an agricultural-type sprayer, shown in figure 3. The sprayer's 500-gal tank provided enough solution to treat a 400- by 45-ft section of road surface at a rate of 0.25 gal/yd^2. The pump had a 160-gal/min capacity at 40 psi and was powered by an 8-hp, four-cycle gasoline engine. Fourteen nozzles were spaced approximately 11.5 in apart on spray bars. The total length of the boom was 12.5 ft. The sprayer was operated at approximately 30 psig when applying the chemicals, except while spraying the resin; when the equipment would only develop a maximum pressure of 20 to 25 psig. At 30 psig,

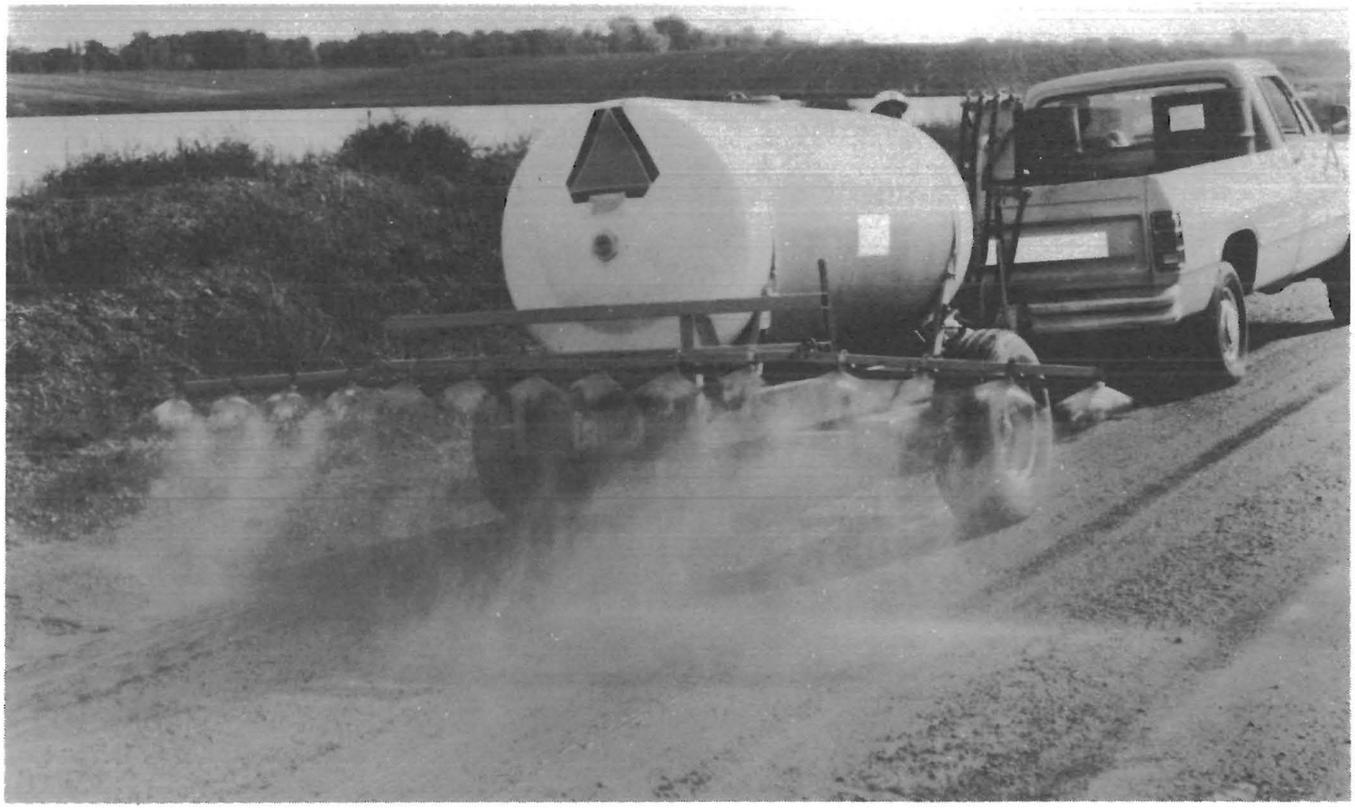


FIGURE 3.—Chemical application by Bureau personnel.

the nozzle pressure was estimated to be 10 psig because of pressure loss through the hoses and fittings. This was estimated by collecting sprayed solution from one nozzle and comparing the result with the manufacturer's published data (6).

The $MgCl_2$ salt was applied by the vendor with a spreader truck normally used for coating asphalt roads (fig. 4). The material was applied at the rate of 0.5 gal/yd^2.

Testing Equipment and Procedures

Two types of testing were performed: dust emission sampling and soil sampling.

Dust Emission Sampling

Dust levels from the haulage roads were measured with GCA RAM-1 dust monitors (fig. 5). The operation and performance of this instrument have been described in the literature (7-8). The instrument can be operated in the three concentration ranges (readout resolution) of 0 to 2, 0 to 20, and 0 to 200 mg/m^3, and in four measurement time constants of 0.5, 2, 8, and 32 s. The RAM-1 was operated without a cyclone precollector for particle size selection, which permitted measuring particles up to 20 µm in diameter.

For the testing described in this report, the monitors were usually operated with a measurement time constant of 2 s and a readout resolution or concentration range in the 0- to 20-mg/m^3 scale. The monitors were placed downwind from the test section, and the readings were recorded on a dual-channel strip chart recorder. Nearly all the testing was done when winds were from a southerly direction. The instruments were then placed on the north side of the road on a berm adjacent to a pond, which ran the entire length of the road (fig. 2). This configuration limited placement of the instrumentation to within 5 m of the road.

The test layout is shown in figure 6, and figure 7 shows the instrumentation in place. Placement of the instrumentation close to the road allowed reading of even low levels of emission during effective control.

FIGURE 4.—Application of $MgCl_2$ salt by the vendor.

FIGURE 5.—GCA model RAM-1 real-time aerosol monitor.

Tests consisted of recording the level of dust generated by haulage trucks passing the test area. The testing was performed periodically during the work-shift to record the potential effects of temperature and humidity over time.

Soil Sampling

The silt content of an open dust source, such as the surface of a haulage road or a tailing basin, is one of the factors that influence the amount of dust generation (5, 9). Silt is defined as the soil material that will pass through a 200-mesh (74-µm) screen by dry sieving (5).

Soil samples were taken by sweeping material from the roadway and dry sieving it on a 200-mesh screen. Analyses of the 13 soil samples are shown in table 3. Road surfaces with silt contents between 4 and 8 pct should be amenable to all types of dust control chemicals (9).

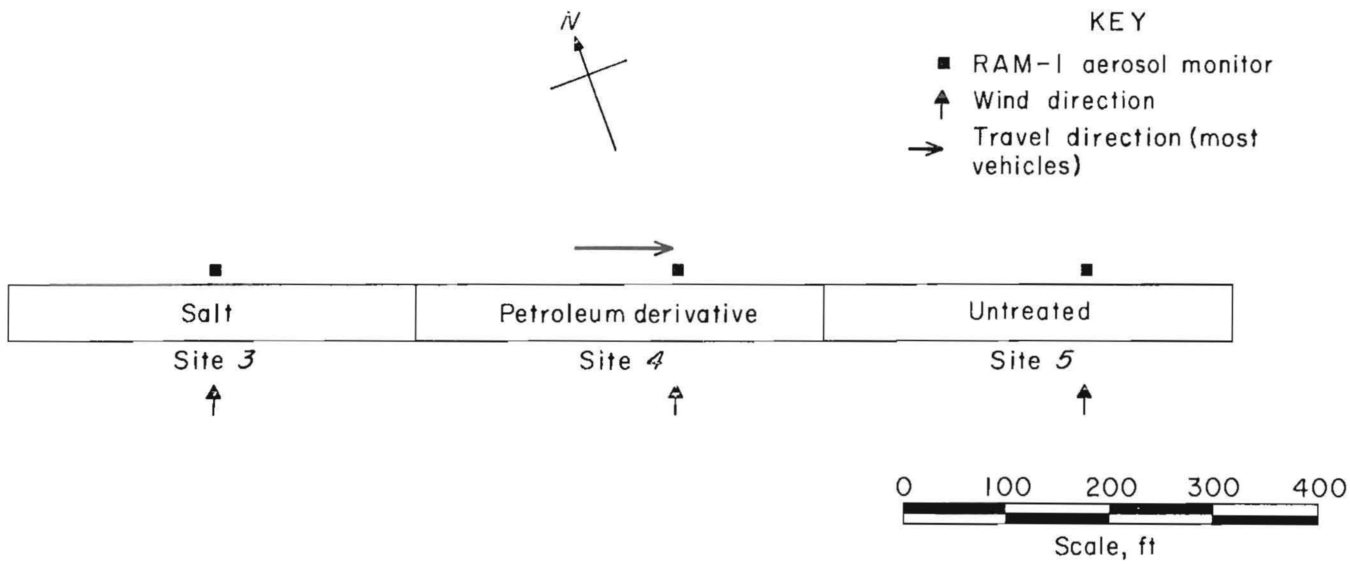


FIGURE 6.—Haulage road dust control test configuration.

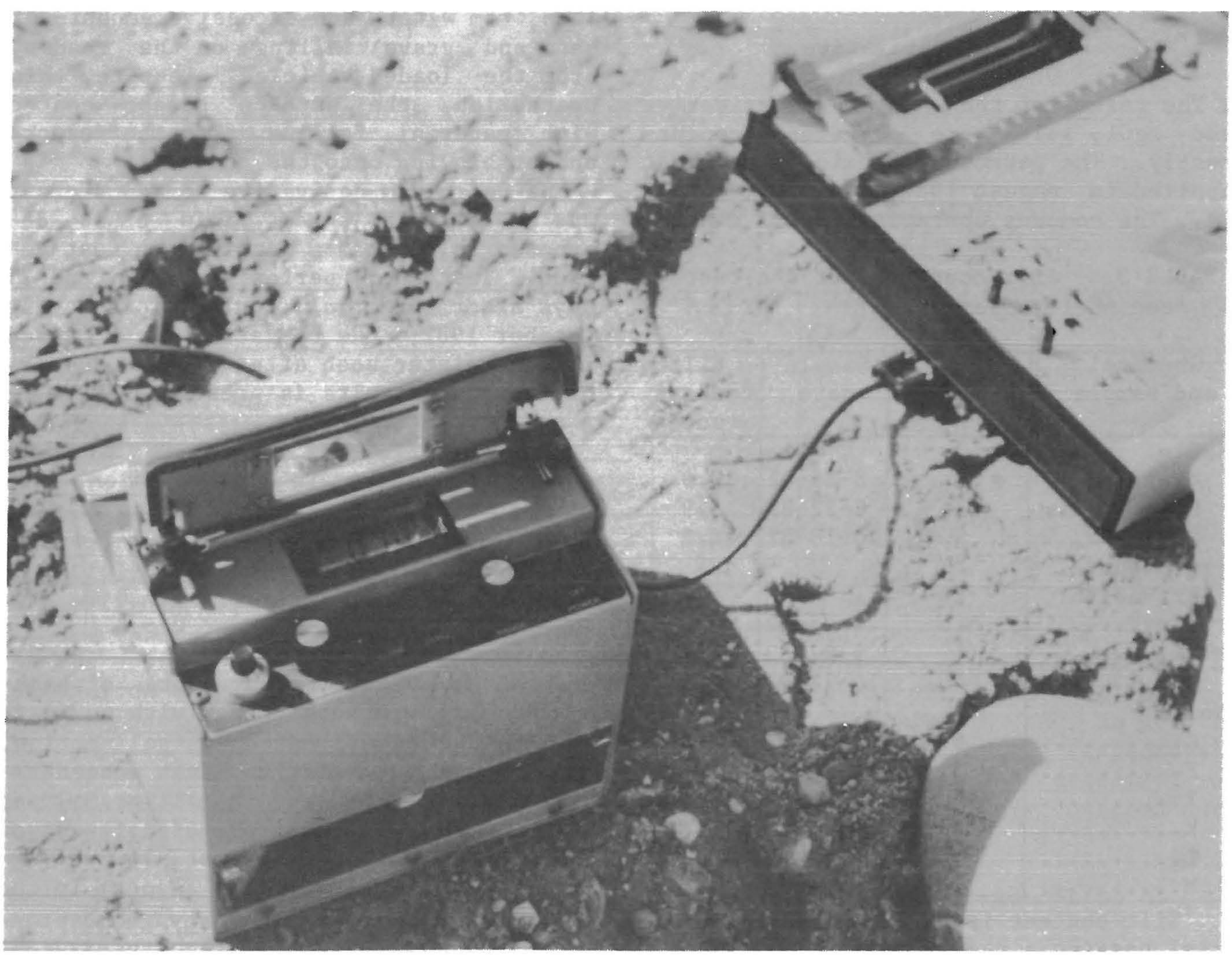


FIGURE 7.—Instrumentation in place during haulage road testing.

Those with silt contents less than 4 pct provide insufficient surface area for adhesive bonding to be effective; those with more than 8 pct silt flex excessively and break any chemical bonds that are formed (9). The silt content from the untreated road sections was between 4 and 8 pct in five of the six sites sampled (table 3).

The moisture contents were also determined in the first nine soil samples and are discussed under the section pertaining to test results from the $MgCl_2$-salt-treated section.

Results and Discussion

The test results are presented for each chemical applied. The data presented in this section are summaries of individual test readings contained in the appendix.

Petroleum Derivative

The tests of the petroleum derivative and $MgCl_2$ salt were performed concurrently. The petroleum chemical was first applied in August 1982, to area 1 (fig. 2). The company operations were changed shortly afterward, which restricted testing at that location. Some exceptionally wet material was hauled from the pit, causing water to fall from the bottom of the trucks along the entire route to the plant, including the treated areas. The road surface became wet and prevented any meaningful testing while this condition existed. The company ceased normal pit operations at the end of August for 2 weeks owing to low demand for sand and gravel. The traffic pattern between the pit and plant was changed when production resumed later that year.

A second application of petroleum derivative was then applied to area 4 (fig. 2) during October 1982 in the same manner as the initial treatment, as this area was part of the road generally used by empty trucks returning to the pit. This change allowed testing without interference from water and excessive amounts of sand and gravel falling on the roadway from the loaded vehicles. Despite this precaution, the surface became coated with material falling from the trucks and/or blowing onto the roadway.

The petroleum derivative formed a crust up to 0.25 in thick. This crust decreased in thickness during the test period. Tests were performed 9, 13, and 21 days after chemical application during October 1982; the operation was closed for the winter soon afterward. A summary of the test results is presented in table 4 and figure 8.

Control efficiency, which is the percentage reduction in dust emission, was used to compare the effectiveness of dust suppressants and is calculated in the following way:

$$\text{Percent efficiency} = \left[1 - \frac{T - B}{U - B} \right] 100$$

B, U, and T are measurements of background (measurements taken with no traffic present), untreated control section, and treated test section dust concentrations, respectively, in milligrams per cubic meter. The control efficiency was 49 pct during the first test, 76 pct during the second test, and 84 pct in the final test. Extremely dusty conditions were encountered during the third test

TABLE 3. - Silt contents[1] of the tested road surface samples

Chemical and sample	Site (fig. 2)	Sample date	Silt content, pct
$MgCl_2$:			
A..........	2	8-25-82	3.9
D..........	2	9-22-82	5.9
G..........	3	10-18-82	2.8
Petroleum derivative:			
B..........	1	8-25-82	4.7
E..........	1	9-22-82	6.4
H..........	4	10-18-82	2.1
None:			
C..........	6	8-25-82	4.4
F..........	5	9-22-82	5.5
I..........	5	10-18-82	5.2
K..........	4	7-14-83	3.3
L..........	4	8- 9-83	4.5
M..........	5	8- 9-83	6.0

[1]Silt content is defined as soil material passing a number 200-mesh screen.

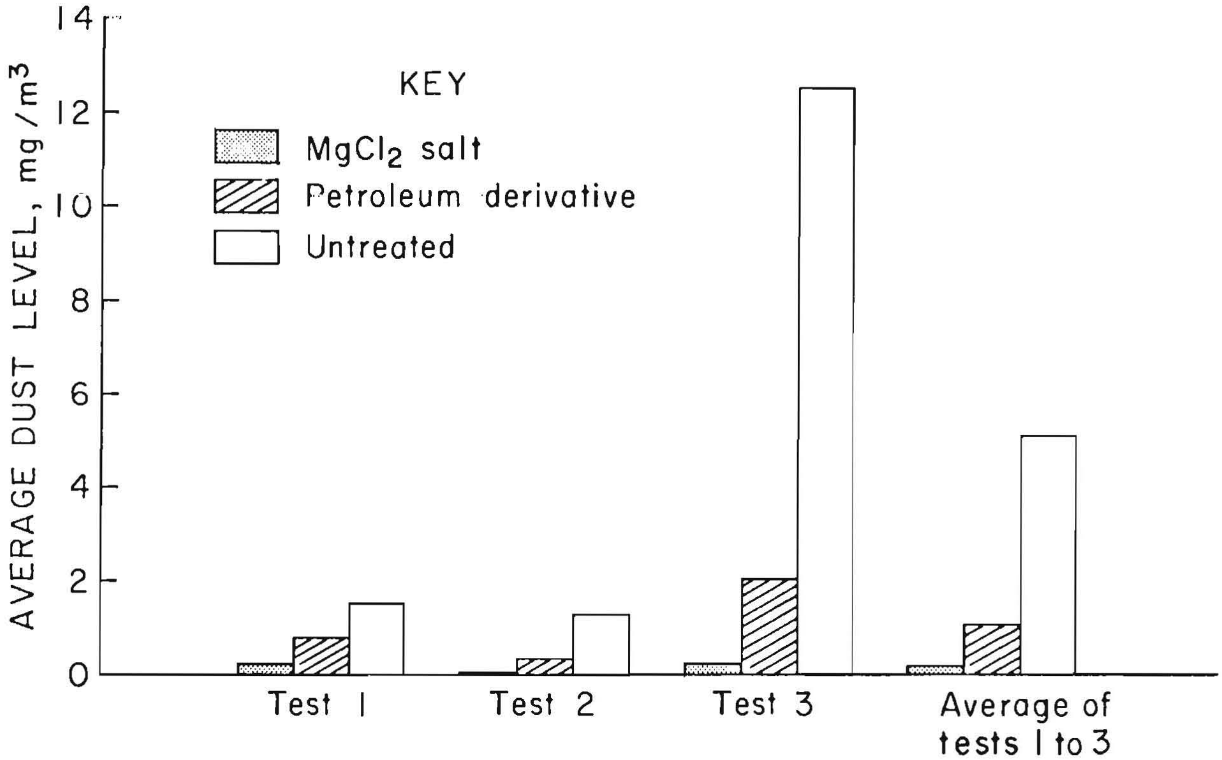


FIGURE 8.—Average dust levels from the petroleum-derivative-treated and salt-treated sections and from the untreated section.

TABLE 4. - Dust emissions from sections treated with $MgCl_2$ salt and petroleum derivative

Treatment and site[1]	Test 1	Test 2	Test 3	Av of 3 tests
Av background......................mg/m^3..	<0.02	<0.02	0.03	0.02
Av dust level, mg/m^3:				
Untreated (site 5).......................	1.52	1.29	12.50	5.10
$MgCl_2$ (site 3)...........................	0.21	0.03	0.20	0.15
Petroleum derivative (site 4)...........	0.79	0.31	2.04	1.05
Control efficiency, pct:				
$MgCl_2$ salt (site 3)......................	87.3	99.2	98.6	95.0
Petroleum derivative (site 4)...........	[2]48.7	77.2	83.9	69.9

[1]From figure 2.

period where the average level of emissions from the untreated section, not including background, was 12.5 mg/m^3. This is compared with 1.5 and 1.3 mg/m^3 during the first and second tests, respectively.

Emissions from the treated section were 0.79 mg/m^3 during the first test, 0.31 mg/m^3 during the second test, and 2.04 mg/m^3 in the third test. Relative humidity was probably the major cause of higher dust levels from both the treated and untreated sections during the third test. The minimum relative humidity on that date was 30 pct at 1500 h, compared with 43 pct at 1800 h and 54 pct at 1500 h during tests 1 and 2, respectively (10). Wind direction and velocity and temperature were relatively constant during the testing.

Magnesium Chloride Salt

The tests with $MgCl_2$ salt were performed concurrently with those of the petroleum derivative. The $MgCl_2$ salt was first applied to area 2 (fig. 2) in August 1982 as described in the "Surface Preparation and Chemical Application" section. That site became unsuitable for the same reasons given in the "Petroleum Derivative" section, and a second application of $MgCl_2$ salt was then performed on area 3 (fig. 2) when normal pit operations resumed. The $MgCl_2$-salt-treated area was adjacent to that treated with petroleum derivative. The tests were performed in October 1982, 10, 14, and 22 days after chemical application, using the methods described in the "Testing Equipment and Procedure" section. Production was halted for the winter shortly after the final test period.

A summary of the $MgCl_2$ salt test results is given in table 4 and shown in figure 8. Under the test conditions, $MgCl_2$ salt with an average emission reduction of 95 pct controlled dust more effectively than the other test chemicals. A demonstration of these results is shown in figures 9, 10, and 11, where

FIGURE 9.—Haulage truck on an untreated section.

FIGURE 10.—Haulage truck on a section treated with petroleum derivative.

FIGURE 11.—Haulage truck on a section treated with $MgCl_2$ salt.

FIGURE 12.—Section of road (foreground) treated with $MgCl_2$ salt approximately 4 weeks earlier.

a haulage truck is first shown traveling on the uncontrolled section, then on the section treated with petroleum derivative, and finally on the section treated with $MgCl_2$ salt.

The control efficiency for the $MgCl_2$ salt was 87 pct 10 days after application and 99 pct both 14 and 22 days after application. Average dust emissions from the area treated with $MgCl_2$ salt were 0.21 mg/m^3 in the first test, 0.03 mg/m^3 in the second test, and 0.20 mg/m^3 in the third test (10, 14, and 22 days after application, respectively).

The hygroscopic and deliquescent nature of the $MgCl_2$ salt was demonstrated by the treated area remaining damp despite the amount of material deposited on the surface. The darker road surface in the foreground of figure 12 shows where the $MgCl_2$ salt had been applied approximately 4 weeks earlier. Note the distinct difference in appearance between the $MgCl_2$-salt-treated surface (darker) and the adjacent petroleum-derivative-treated surface (lighter). The effect continued until the operation closed for the winter, approximately 1 month after chemical application. Further observations were impossible because the entire area was covered by snow.

Moisture analysis was performed on nine soil samples from areas treated with $MgCl_2$ salt and petroleum derivative and from the untreated area to determine the hygroscopic effect of the $MgCl_2$ salt. The results of this analysis are shown in table 5. The moisture retention capability of the salt is evidenced by higher average moisture contents than those from areas left untreated or those treated with the petroleum derivative. The average moisture content from samples with $MgCl_2$ salt treatment exceeded that of samples from untreated sections by 150 pct and that of samples from the petroleum-derivative-treated area by 240 pct. Sample D shows a lower moisture level than the other samples from the $MgCl_2$-salt-treated area because the sample was taken 39 days after the chemical application.

TABLE 5. - Moisture contents of soil samples from sections treated with $MgCl_2$ salt and petroleum derivative and from the untreated sections

Chemical treatment and sample	Site (fig. 2)	Moisture content, pct	Days after application
$MgCl_2$:			
A.........	2	1.60	12
D.........	2	.71	39
G.........	3	1.44	13
Petroleum derivative:			
B.........	1	.37	14
E.........	1	.37	41
H.........	4	.36	14
None:			
C.........	6	.79	NAp
F.........	5	.15	NAp
I.........	5	.55	NAp

NAp Not applicable.

Resin

Two applications of the resin were made on area 3 (fig. 2), and testing was initiated on July 6, 1983, 5 days after the second application. A third application was required 5 days later because of a heavy rainfall. Three tests were conducted before resin testing was discontinued because the average dust level from the treated area was 10.5 mg/m^3 compared with only 5.1 mg/m^3 for the untreated section (area 4, figure 2). The chemical was not effective under existing conditions; however, the lack of favorable results does not preclude possible resin use where soil types are different and/or traffic conditions are less severe.

Wetting Agent

The fourth chemical tested was a wetting agent added as a dilute solution (3,000:1) in the water normally applied to the haulage roads for dust control. The wetting agent was applied in a different manner than the other chemicals tested because of the temporary nature of its control. The wetting agent solution was applied prior to each day's testing on one section of road, and an adjacent section was treated with an equal amount of water. Dust levels were determined in the same manner as with the other chemical treatments, and comparisons were made only between the treated section and the untreated (watered) section. Dust levels were recorded during the 4 days of testing. Information concerning dates and locations of the tests appears in table A-3.

After two tests, the section treatment was reversed to compensate for variations in the road surface and traffic pattern between the two areas. Sufficient time was allowed between the switching of test areas to prevent any carryover effect from the wetting agent. Comparisons were made at regular intervals following chemical or water application (table 6). A direct comparison of simultaneous readings from the two areas was not possible because of the time required to treat the two test sections and the rapid evaporation of moisture from the road surface. There was no significant difference

TABLE 6. - Average dust levels after application of wetting agent and water

Elapsed time, min	Av dust level, mg/m^3	
	Wetting agent	Water only
31-45........	0.10	ND
46-60........	.57	0.75
61-75........	1.25	1.45
76-90........	1.62	2.24
91-105.......	1.44	1.63
106-120.......	1.22	1.42
121-135.......	3.18	2.66
136-150.......	4.94	3.90
151-165.......	4.12	3.10
166-180.......	4.20	3.91
181-195.......	2.12	4.85
196-210.......	4.70	5.42
211-225.......	5.74	4.22
226-240.......	5.87	ND
241-255.......	5.67	ND
Mean.......	2.81	2.74

ND Not determined.

NOTE.--All averages are geometric means.

between the dust levels generated from the two types of treatment (fig. 13).

A complete study of this type of chemical road dust control would involve a considerable amount of testing, including various dilution ratios and application rates, effect of weather conditions, and carryover effects from continuous long-term application of the product. Such a study is outside the scope of this project.

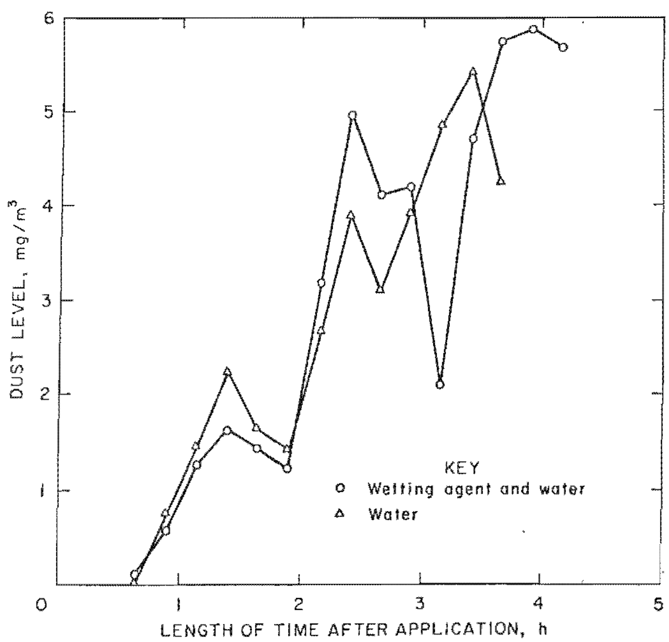


FIGURE 13.—Dust control measured for 4 h following application of water and wetting agent.

Cost Analysis

The cost of chemical dust suppressants must also be considered in addition to their effectiveness. The cost analysis of chemicals used in this study is shown in table 7 and was estimated using the following assumptions.

The estimated labor and equipment costs associated with road surface preparation and chemical application were based on those developed in a recent Bureau of Mines-sponsored research effort (4). Surface preparation cost for applying the $MgCl_2$ salt, petroleum derivative, and resin was $600 per mile. The cost of applying these chemicals was estimated at $90 per application. The cost of applying wetting agent was estimated at $7 per application, the same as the cost of applying water. This analysis does not include the cost of obtaining water used in chemical application.

For the petroleum derivative, the application rate was 1.0 gal/yd^2 of 20-pct solution (4:1 dilution). The manufacturer has discontinued production of the tested product. Cost data for Coherex, another petroleum product applied at approximately the same rate, have been substituted. No other comparison between the two chemicals is being claimed. The cost per mile was estimated at $9,490.

The assumed application rate of $MgCl_2$ salt was 0.5 gal/yd^2 of 32-pct solution as received from the vendor. The $MgCl_2$ salt was the most successful chemical in reducing dust at an application cost of $7,026 per mile. The shipping cost was very significant. Transportation costs to a Midwestern location were 150 pct of the purchase price. The higher shipping costs were incurred owing to handling the product in a dilute solution as opposed to a more concentrated form for the other chemicals tested.

For the resin, one application of a 1-pct prewetting solution followed by one

TABLE 7. - Cost comparison of four dust suppressant chemicals based on a haulage road 1 mile long by 50 ft wide

	Petroleum derivative	$MgCl_2$ salt	Resin		Wetting agent
			Pretreatment	Resin	
Dilution ratio, water-chemical.......	4:1	None	100:1	24:1	3,000:1
Solution application rate...gal/yd^2..	1.0	0.5	0.25	[1]0.50	0.25
Amount of chemical required.....gal..	5,867	14,667	73	587	2.4
Product cost:					
Chemical...................$/gal..	[2]1.20	0.175 ~~1.75~~	17.71	14.79	4.00
Shipping[3]..................$/gal..	0.30	0.26	0.96	0.92	0.88
Total[4]......................$/mi..	8,800	6,336	([5])	10,585	12
Labor and equipment cost[6]......$/mi..	690	690	([5])	870	7
Total application cost[7]........$/mi..	9,490	7,026	([5])	11,455	19

[1]2 applications of 0.25 gal/yd^2 each.

[2]Manufacturer has discontinued this product since testing; therefore, cost data for another petroleum product (Coherex) were substituted here. No other comparison is intended.

[3]From manufacturing plant to Minneapolis-St. Paul, MN.

[4]Total cost = (chemical cost + shipping cost) × (amount of chemical required).

[5]Total cost included with resin chemical cost.

[6]Surface preparation (all chemicals) = $600 per mile; each chemical application = $90 per mile; each application of water = $7 per mile (4).

[7]Cost of water used for dilution is not included.

application of resin diluted to 24:1 with water and two applications at 32:1 dilution were assumed. All resin applications were at 0.25 gal/yd^2 of solution. The estimated cost per mile was $11,455.

The estimated cost of a single wetting agent application is $19, which is considerably less than for any other chemical tested. However, the wetting agent is an additive to water used for haul road dust suppression and, therefore, would normally be applied one or more times each day depending on the road conditions.

The frequency of application required to maintain an adequate level of control was not determined for any of the dust suppressant chemicals tested. The frequency of chemical application will vary according to operational factors such as weather and climatic conditions, type and amount of traffic, vehicle speed, type and condition of road surface, application method, and material deposited on the roadway. Both applications of $MgCl_2$ salt were effective up to 1 month after chemical application. Dust control efficiency of 99 pct was obtained from the $MgCl_2$-salt-treated section 21 days after application, and an 84-pct control efficiency was obtained from the petroleum-derivative-treated section 22 days after application.

AERODYNAMIC MODIFICATIONS TO HAULAGE TRUCKS

The second area of haulage road dust control investigation was aerodynamic modifications to haulage trucks. A literature search was conducted to obtain information on the effects of aerodynamics on fugitive dust generation from haulage trucks and aerodynamic devices that could be added to haul trucks to reduce these dust levels. Most sources related to aerodynamics of highway trucks and automobiles dealt with improving fuel economy (11-14). Several devices were considered for experimentation. A Reddaway-type fender (11) was selected to determine if dust could be controlled by enclosing the wheel to prevent dust from escaping. The Reddaway fender is used to control water sprays from large highway trucks traveling on wet pavement. The advantages of this device include easy installation and ready access to the wheels. The Reddaway fender consists of panels in front of and behind the wheel and a side panel that extends down over the upper surface of the wheel. Several variations are possible in the construction and use of this fender. Further enclosure of the wheel can be achieved by extending the side panel down to the base of the front and rear panels and enclosing the inner side of the fender below the axle. An exploded view of a Reddaway fender is shown in figure 14.

Fender Construction

Two fenders were fabricated from sheet aluminum and steel angle stock as shown in figure 14. The test fender was designed for rapid installation on a single-axle dump truck (fig. 15). Additional wheel enclosure was obtained by a temporary extension of the side panel to the base of the back and front panels, which are about 4 in from the road surface (fig. 16). The inside of the fender below the axle was also temporarily enclosed to the same point.

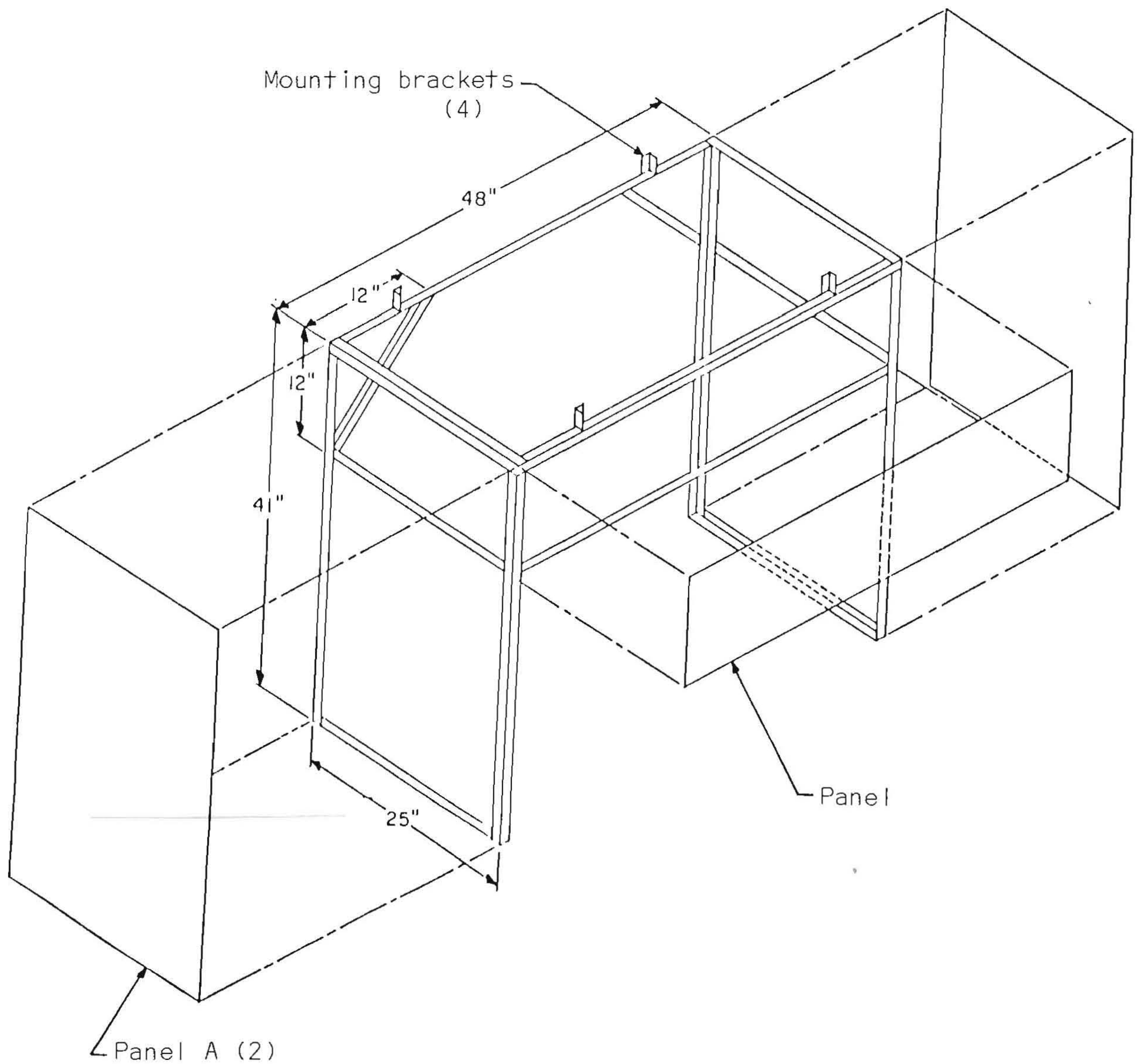


FIGURE 14.—Exploded view of Reddaway-type fender.

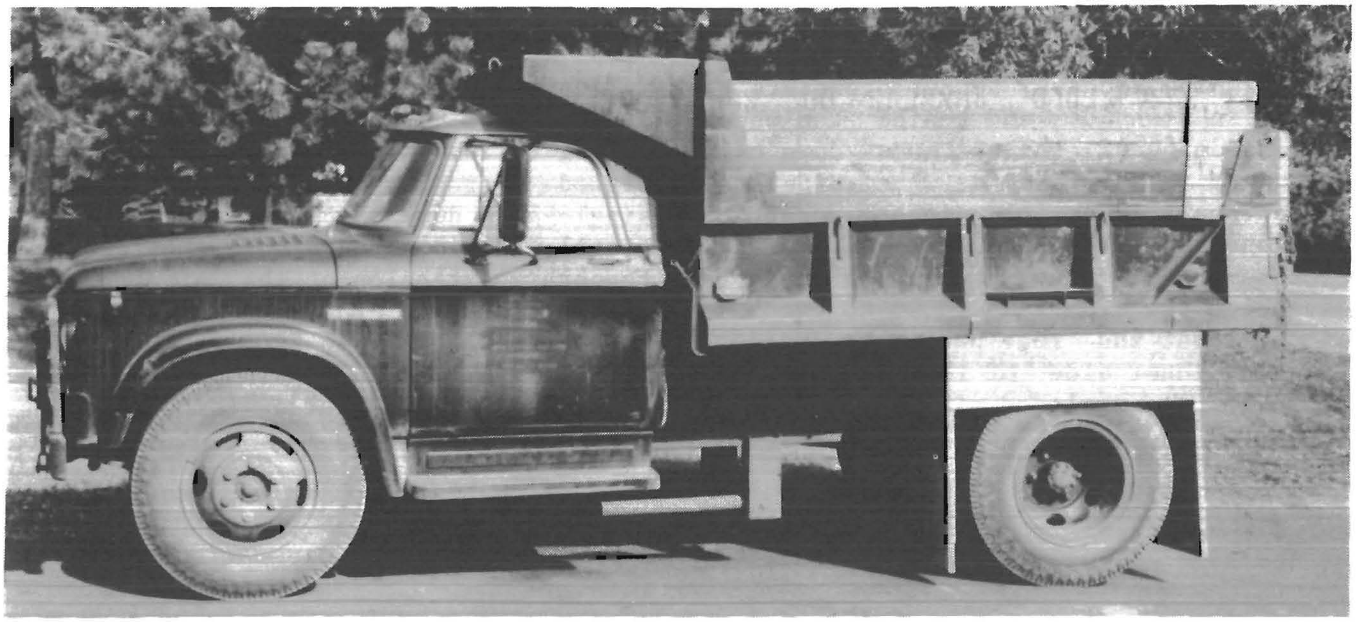


FIGURE 15.—Bureau dump truck fitted with Reddaway-type fender.

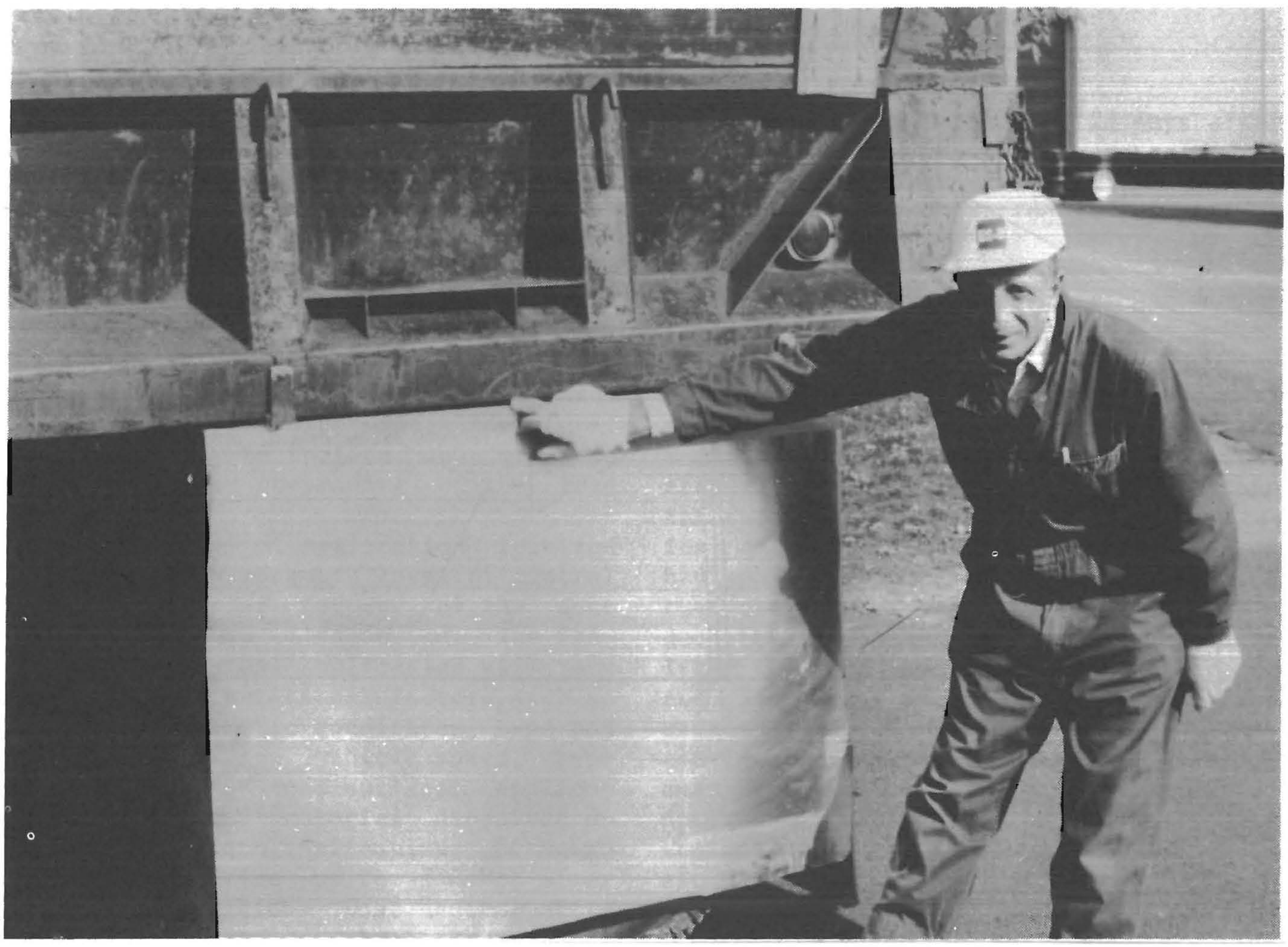


FIGURE 16.—Reddaway-type fender with additional wheel enclosure for testing purposes.

Field Testing

The dust control effectiveness of the Reddaway fender was tested at area 4 (fig. 2) in the same manner as the dust suppressant chemicals described earlier. A 5-yd^3-capacity, single-axle dump truck was used to simulate a mine haulage truck. The fenders were bolted to the truck box (fig. 17). The tests were performed on a section of haulage road surface that was not chemically treated and was not watered prior to testing.

The testing configurations included no wheel enclosure, standard mud flaps, the fender as initially constructed, and the fender with extended side panels. The test also included measurement of dust emissions from a mine haulage vehicle.

Test Results

The results of the aerodynamic testing using various configurations of wheel enclosure are contained in table 8. These data indicate that the fender, either as constructed or modified, did not significantly reduce dust levels. With the fenders the dust pattern formed an acute angle with the road surface toward the rear of the fenders, permitting dust to escape through the 4- to 6-in space

TABLE 8. - Dust emission measurements from a 5-yd^3 dump truck fitted with various fender configurations and from a mine haulage vehicle

	Av dust level, mg/m^3	Std dev, mg/m^3
Fender and/or flap configuration on truck:		
None....................	1.13	0.34
Standard mud flaps.....	.70	.04
Reddaway fender........	1.02	.33
Extended Reddaway fender................	1.05	.35
Mine haulage vehicle.....	.96	.44

NOTE.--All tests with Bureau dump truck at 30 mi/h.

FIGURE 17.—Field testing the Reddaway-type fender.

between the base of the fender and the road surface and billow away from the truck (fig. 17). The lowest dust concentration was achieved during this series of testing when using standard mud flaps. This reduction (from 1.13 to 0.70 mg/m^3) may be due to the flaps extending back from the truck and partially intercepting the flow of dust.

No additional testing of aerodynamic modifications to haulage trucks was performed because of a change in the Bureau's mission with respect to fugitive dust.

TAILING BASIN DUST CONTROL

Tailing disposal areas have been cited as a major source of fugitive dust from mining operations (1). Tailing is a waste product resulting from the processing of metal ores such as iron, copper, lead, zinc, and uranium. The tailing wastes are normally deposited in a basin as a slurry. If the tailing material remains exposed and is allowed to dry, it becomes susceptible to wind erosion. Coarse particles become dislodged by the wind and move by saltation (the bouncing and jumping motion of wind-blown particles), in turn dislodging finer particles (usually less than 100 µm), which then become airborne. Chemical dust suppression is a major method of controlling dust from tailing material surfaces. A description of the chemical and physical properties of the tailing dust control chemicals used in the contract and in-house research is given in table 9.

The Bureau awarded a contract (contract J0218024) to Environmental Services and Technology of Kansas City, MO, to determine the state-of-the-art in chemically stabilizing active tailing basins in the United States, develop criteria enabling

TABLE 9. - Chemical and physical properties of dust suppressant chemicals used in tailing basin dust control research

Dust suppressant chemical	Trade name	General appearance of liquid	pH	Sp gr, g/cm^3	Flash-point, °C	Boiling point, °C	Generic description
Lignin sulfonate.	Flambinder	Dark brown, viscous.	3.0-3.5	1.17	None	110	55 pct calcium lignin sulfonate, 27 pct sugars, 3.5 pct CaO, 5 pct S.[1]
Lime-neutralized lignin sulfonate.	Flambinder NX.	...do.....	7.0	1.17	None	110	55 pct calcium lignin sulfonate, 6.4 pct CaO, 5 pct S.[1]
Petroleum resin.	Coherex...	Yellow....	7.1	1.00-1.04	204	100	60 pct petroleum resin, 40 pct wetting agent.
Latex.......	Nalco 655.	White, viscous.	NA	1.02	93	90	High-molecular-weight acrylamide-modified polymer in emulsion form.
Do........	Nalco 656.	...do.....	8.0	1.05	>93	98	High-molecular-weight anionic acrylamide-modified polymer in emulsion form.
$MgCl_2$.......	Dustgard..	Clear.....	7.0	1.32	None	100	32 pct $MgCl_2$.

NA Not available.

[1]The percentages shown are for a typical sample of chemical and pertain to the composition of solids which constitute approximately 50 pct of the lignin sulfonate and lime-neutralized lignin sulfonate.

the optimum selection of chemicals for stabilizing tailing basin surfaces, and field-test the validity of these criteria. The results are published in a final report (5). A brief summary of that report is included because the Bureau's in-house research on the effect of the chemicals on vegetative stabilization of tailing basins was an extention of that contract effort.

DUST CONTROL ON ACTIVE TAILING PONDS

State-of-the-Art Survey and Criteria Development

The project (contract J0218024) was designed to develop field evaluation criteria to determine the effectiveness over time of chemical stabilizers, and, through field tests described below, to validate these criteria and evaluate the effectiveness of several types of chemical dust suppressants.

The first phase of the study consisted of acquiring information on tailing basin dust control from the published literature and contacts with vendors of chemical stabilizers and application equipment. A number of mining companies were also questioned about their experiences with tailing basin dust control. Few domestic mining companies have had tailing basin dust control programs for more than 5 years, but many are conducting studies to establish dust control measures. Many of these experimental programs have been inconclusive because a means of testing the effectiveness of chemical stabilizers over time is generally not available.

The major types of chemical dust suppressants used to control fugitive dust from tailing basins are (1) lignin sulfonates, (2) petroleum resins, (3) latexes, (4) salts, (5) plastics, and (6) wetting agents.

The following parameters and evaluation criteria were selected to determine the ability of various chemical dust suppressants and soil stabilizers to control dust and their cost effectiveness: dust control effectiveness; meteorology; tailing characteristics; product usage requirements; and product, labor, and equipment costs.

Dust Control Effectiveness

The dust control effectiveness of a chemical stabilizer is a major factor in selecting it as a tailing dust suppressant. The effectiveness of a dust control chemical is determined by its ability to control dust over a specified time period. In this case, the time period was a wind erosion season of 4 months. Wind erosion threshold velocity measurements and emission factor measurements are designed to determine the effectiveness of a chemical over the lifetime of its application. Both are explained in the "Field Test" section.

Meteorology

The meteorology conditions during the lifetime of the applied chemical dust suppressant govern its long-term effectiveness. The major meteorological parameters are precipitation, wind direction and velocity, and temperature. Relative humidity, which may affect long-term dust control efficiency, could not be properly evaluated in this study.

Tailing Characteristics

Two characteristics of the tailing material that should be evaluated before selecting a chemical dust suppressant are the silt and moisture contents. Coarse tailing material (less than 5 pct silt) usually requires no chemical stabilization. Dry tailing material (less than 0.75 pct moisture) is susceptible to wind erosion and requires some form of stabilization.

Product Usage Requirements

Before selecting a chemical stabilizer, an evaluation of the associated usage requirements of the chemical is needed. This will identify potential problems in delivery, storage, handling, and application of the chemical.

Costs

The total cost of a tailing dust control program includes expenditures for product, labor, and equipment. Product cost includes the base cost of the chemical plus shipping cost, which can be significant depending on the distance from the shipping point and the amount of chemical required. In this study, the labor and equipment costs were estimated at $30 per acre, although it is recognized that this amount may vary considerably.

Cost Effectiveness

After assessing the merits of the chemical stabilizers according to the previously mentioned selection criteria, the cost effectiveness of the most suitable chemicals should be estimated. A cost-effectiveness evaluation consists of determining the total product, labor, and equipment costs necessary for the application and maintenance of chemical stabilizers to achieve a desired level of dust control during a wind erosion season.

Field Testing

Site and Chemical Selection

A tailing basin at the National Steel Pellet Co., operated by the M. A. Hanna Co. near Keewatin, MN, was selected as the field site. Eight 0.5-acre plots (208 by 104 ft) were selected for chemical application and testing. An untreated test plot approximately 25 by 208 ft in the center of the test area was used for control. A general layout of the test plots and chemicals used on each plot is shown in figure 18.

The application rate and dilution ratio for each of the five test chemicals are given in table 10. The chemical solutions were applied to the tailing surface on May 25 and 26, 1982, with a high-flotation-spray vehicle, shown in figure 19.

Petroleum resin and calcium lignin sulfonate were chosen because of their prevalent use by the mining industry. Two strengths of each chemical in solution were used to determine the effects of dilution over time. Two similar latex chemicals of the type used by the mining industry in northern Minnesota were also selected. The fifth chemical selected was $MgCl_2$ salt, a relatively new dust suppressant which is a byproduct of NaCl and K_2SO_4 production, manufactured from Great Salt Lake brines (15). The $MgCl_2$ salt was applied to a dry tailing surface on one plot and to a tailing surface moistened to a depth of 0.5 in on an adjacent plot, to evaluate the necessity

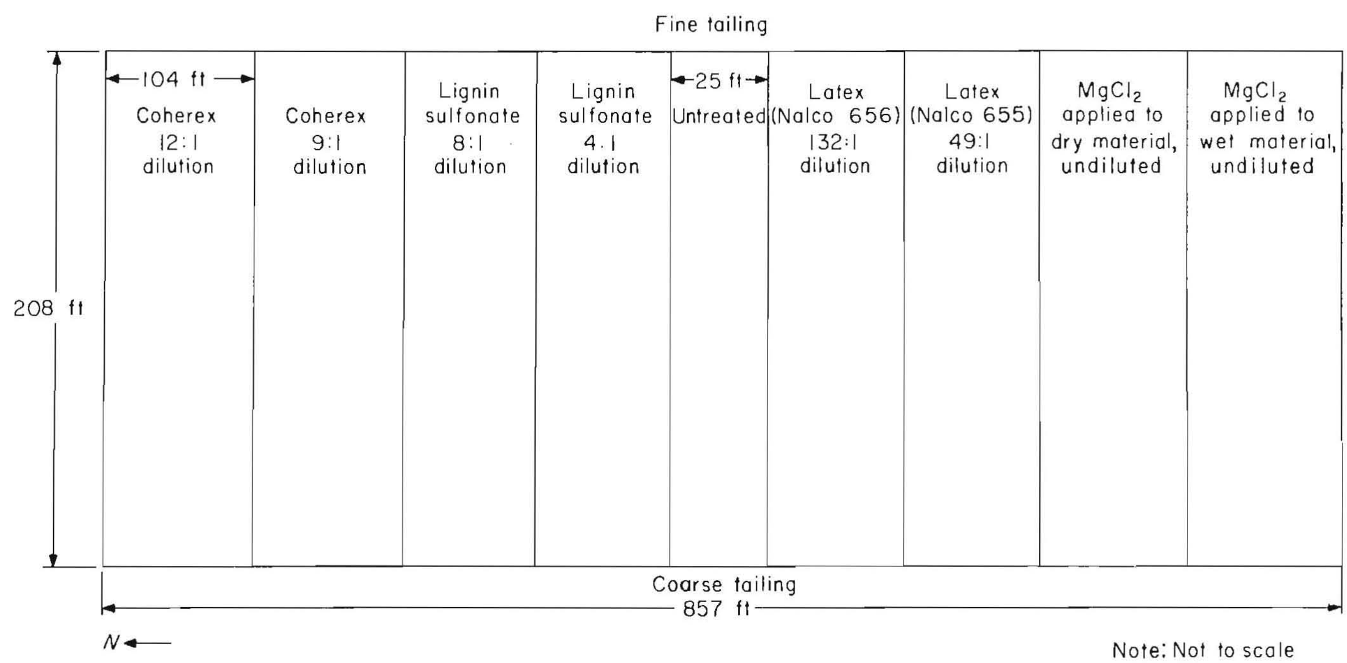


FIGURE 18.—Test plot location and size—contract JO218024.

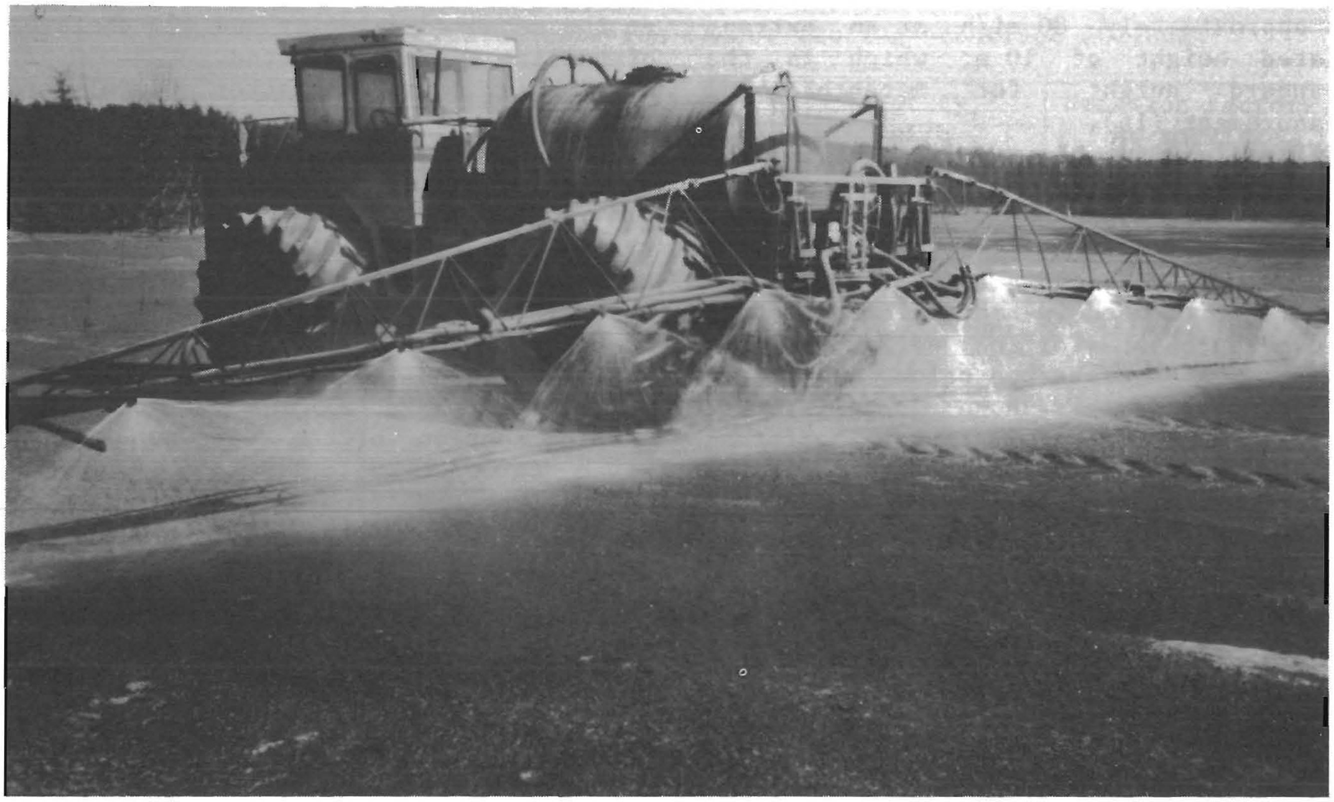


FIGURE 19.—Application of dust control chemical on tailing material—contract JO218024.

TABLE 10. - Field testing tailing basin dust control chemical dilution and application rates--contract J0218024

Dust suppressant chemical	Trade name	Dilution ratio, water:chemical	Chemical application rate[1]	
			lb/acre	gal/acre
Petroleum resin....	Coherex......	12:1	790	95
Do...............	...do........	9:1	1,030	120
Lignin sulfonate...	Flambinder...	8:1	1,310	135
Do...............	...do........	4:1	2,370	240
Latex..............	Nalco 655....	49:1	210	25
Do...............	Nalco 656....	132:1	80	10
$MgCl_2$ salt.........	Dustgard.....	[2]None	26,620	2,420

[1]Solution application rate was 1,210 gal/acre (0.25 gal/yd^2) for all chemicals requiring dilution with water.
[2]A 32-pct $MgCl_2$ salt solution applied without dilution.

of applying the chemical to a damp surface for efficient dust control.

Sampling Method

A portable wind tunnel (fig. 20) was the primary instrument used to determine the long-term effectiveness of the chemical stabilizers. The working section of the wind tunnel was constructed of plexiglass, 8 ft long and 6 in square. The bottom was open and was placed directly on the tailing surface. Air was drawn through the working section to erode the tailing surface and suspend the fine particles. Wind speeds up to 50 mi/h could be generated within the working section. This velocity is equivalent to approximately 80 mi/h at an extrapolated height of 10 m, which is the standard height for meteorological measurement (16).

After leaving the working section, the particle-laden air entered the test section of the wind tunnel and was sampled isokinetically. A flow-splitting device and a 10-stage quartz crystal cascade impactor were used in particle collection and measurement for the emission factor measurements described below. The field test apparatus is shown in figure 20. Two types of measurements were performed to determine dust control effectiveness--emission factor measurements and wind erosion threshold velocity tests.

An emission factor is defined as the amount of emissions per unit of source activity. The emission factors developed in this study are expressed in grams per minute per square meter ($g/(min \cdot m^2)$) of tailing surface. Two units of source activity are required to use these emission factors for quantifying dust generation: (1) the length of time the wind speed is at the measured velocity and (2) the area of tailing surface affected.

Thirteen emission factor tests were performed on six of the nine test plots at various times during the field test program. The results are shown in table 11. The sampling method was similar to EPA test procedure method 5 (17) and consisted of performing a nine-point collection traverse within the working section of the wind tunnel. Sampling was performed at wind velocities equivalent to 40 to 50 mi/h at a 10-m height. The working section of the wind tunnel was moved for each velocity test to sample surface material from which the fines had not been removed by previous testing. Tests were performed for a specified length of time, and the emission level was calculated.

Emission factors were computed for particles <12 μm and <2.1 μm. These particle sizes are the two size fractions from the quartz crystal cascade impactor that most closely match the coarse (2.5- to 15-μm) and fine (<2.5-μm) fractions

FIGURE 20.—Wind tunnel and instrumentation for determining wind erosion threshold velocities and for performing emission factor tests—contract J0218024.

TABLE 11. Wind erosion emission factor testing--contract J0218024

Test	Dust suppressant chemical and dilution[1]	Time since application,[2] days	Tailing properties, pct		Velocity,[3] mi/h		Emission factors,[4] at particle diameter of--	
			Moisture	Silt	Threshold	Test	<12 µm	<2.1 µm
	Petroleum resin:							
1...	12:1	3	0.26	0.05	53	50	2.02	1.23
2...	9:1	3	.38	.05	53	50	2.63	1.28
4...	12:1	21	.46	1.6	32	40	77.2	7.16
5...	12:1	21	.46	1.6	32	40	16.2	2.13
6...		21	.28	4.3	46	50	.881	.096
	Lignin sulfonate:							
3...	8:1	3	.32	4.4	50	50	2.68	2.58
7...	8:1	21	.35	2.3	31	40	1.50	.180
15...	8:1	63	.28	3.3	43	50	283	54.0
16...	8:1	63	.30	.3	46	50	1,360	216
18...	Latex (Nalco 655)	64	.10	1.3	45	50	116	18.2
19...	$MgCl_2$ salt[5]......	64	.57	6.5	31	40	1,500	213
42a..	Uncontrolled.....	--	.37	.5	40	45	73.8	17.2
43...	...do............	--	.35	1.0	43	50	25.6	3.10

[1]Dilution ratio shown only where 2 different strengths of the same chemical were applied.
[2]Petroleum resin and lignin sulfonate were applied on May 25, 1982, and the latex and $MgCl_2$ salt were applied on May 26, 1982.
[3]Calculated for a 10-m height.
[4]Expressed as 10^{-3} g/(min•m^2). [5]Applied to a dry surface.

measured by the dichotomous sampler used for ambient aerosol monitoring (18).

An example emission inventory calculation for estimating the amount of <12-µm material entrained from two hypothetical tailing areas follows. One area was recently treated with a chemical dust suppressant and has an emission factor for <12-µm material of 0.0162 g/(min•m^2) at a wind velocity of 40 mi/h at an equivalent 10-m height. The second area has lost most of its bonding strength from a previously applied chemical and has an emission factor of 1.5 g/(min•m^2) at the same velocity. A windstorm occurs with 40-mi/h gusts. The emission factor of each tailing area is multiplied by the total time of the 40-mi/h wind gusts (assume 10 min) and the number of square meters in an acre (4,047 m^2 = 1 acre). The emissions of <12-µm material resulting from the storm for the recently treated area would be 0.66 kg/acre, compared to 60.7 kg/acre for the other plot.

Wind erosion threshold velocity tests were used to compute the control efficiency during the lifetimes of the various chemical applications. Wind erosion threshold velocity is the speed when saltation begins and the tailing particles begin to move. This was determined by observing the tailing surface through the top of the plexiglass working area of the wind tunnel and recording the wind velocity at which movement was noted.

The control effectiveness was determined by assuming a 100-pct control immediately following chemical application. Threshold velocity measurements were taken six times during the next 4 months, and the data were normalized by setting the lowest threshold velocity value for that particular plot equal to a control efficiency of 0. The lowest threshold velocity value usually occurred during the final test period and was always within the range of the threshold velocities measured for the untreated tailing material.

The formula used to calculate the control efficiency using the normalized threshold data for a particular period was--

$$\text{Pct control efficiency} = \left[\frac{V_{ti} - V_{tc}}{V_{ti}} \right] \times 100$$

where V_{ti} = threshold velocity from the initial test period, mi/h

and V_{tc} = threshold velocity from the current test period, mi/h

The mean dust control efficiency for each chemical treatment, 2 and 4 months after application, is shown in table 12.

Cost Effectiveness

The cost effectiveness of each dust suppressant chemical was computed in terms of dollars per acre (product, labor, and equipment). Two levels of dust control were selected--90+ pct (considered the maximum attainable control level) and 75 pct. The minimum period considered was 90 days, which is the approximate length of the peak spring and fall wind erosion periods in northern Minnesota. A minimum of two such treatments each year are required to provide protection during those peak emission periods. Additional applications may be necessary during the summer if precipitation does not keep the tailing moist and during the winter if the snow cover is insufficient to prevent dust generation. The results of the cost-effectiveness analysis of the chemicals tested are shown in table 13.

EFFECTS OF CHEMICAL DUST SUPPRESSANTS ON REVEGETATION

The Bureau evaluated vegetative response on Minnesota taconite tailing material that had been chemically treated to control dust generation. The objective of this research was to compare vegetative response (germination, emergence, and growth) on untreated tailing material with that achieved on material with chemicals found acceptable in earlier research (under contract J0218024) involving chemical dust control on active tailing basins (5).

Tailing material is generally stabilized either by chemical addition, to control dust temporarily, or by vegetation establishment, which can be either

TABLE 12. - Mean chemical dust control percent efficiency 2 and 4 months after application--contract J0218024

Dust suppressant chemical	After 2 months	After 4 months
$MgCl_2$ salt applied to--		
Wet surface..........	82	66
Dry surface..........	65	48
Latex:		
Nalco 655...........	69	48
Nalco 656...........	67	47
Lignin sulfonate:		
4:1 ratio...........	61	44
8:1 ratio...........	57	38
Petroleum resin (Coherex):		
9:1 ratio...........	54	38
12:1 ratio..........	43	31

temporary or permanent in design. In areas subject to severe wind and/or water erosion, chemical dust suppression soon loses its effectiveness, and tender, emerging vegetation is quickly destroyed by the eroding nature of wind- and water-borne tailing particles.

This study was designed to determine the effect of chemical dust suppression on vegetation planted on the tailing. If the chemical treatment will not prevent seed germination and growth (but will perhaps even enhance vegetation development in some cases) and will protect the vegetation in its tender, young stages by controlling dust, then by the time the chemical dust suppression effect has worn off, the vegetation should be sufficiently developed to control dust generation.

The investigations consisted of (1) laboratory growth chamber research to evaluate the effects of acceptable dust control chemicals on vegetation and (2) field tests on a northern Minnesota taconite tailing basin. The latter tests were reduced to a cursory status because the Bureau discontinued research in mineland revegetation and fugitive dust control, and long-term field testing was impossible.

Laboratory Studies

Laboratory studies conducted by the Bureau evaluated the impacts of successful

TABLE 13. - Dust suppressant chemical cost-effectiveness evaluation for 75- and 90+-pct levels of control during a peak 3-month wind erosion season on the Mesabi Iron Range and in the Western United States--contract J0218024

Dust suppressant chemical and dilution ratio	Initial cost,[1] $/acre	Subsequent applications[2]				Total cost[3] per 3-month season, $/acre	
		Number		Cost, $/acre			
		75 pct	90+ pct	75 pct	90+ pct	75 pct	90+ pct
MESABI IRON RANGE (NORTHERN MINNESOTA)							
Petroleum resin (Coherex):							
12:1	170	2	3	340	510	510	680
9:1	210	1	2	210	420	420	630
Lignin sulfonate:							
8:1	65	1	2	65	130	130	195
4:1	95	1	1	95	95	190	190
Latex:							
Nalco 655, 49:1	230	1	1	230	230	460	460
Nalco 656, 132:1	110	1	1	110	110	220	220
$MgCl_2$ salt (undiluted)	[4]1,075	1	1	555	555	1,630	1,630
WESTERN UNITED STATES							
Petroleum resin (Coherex):							
12:1	170	2	3	340	510	510	680
9:1	212	1	2	215	425	425	635
Lignin sulfonate:							
8:1	140	1	2	140	280	280	420
4:1	225	1	1	225	225	450	450
Latex:							
Nalco 655, 49:1	230	1	1	230	230	460	460
Nalco 656, 132:1	110	1	1	110	110	220	220
$MgCl_2$ salt (undiluted)	[4]625	1	1	330	330	955	955

[1]Includes chemical cost, shipping, and cost of chemical application.

[2]Application rate 1,210 gal/acre (0.25 gal/yd^2) in all cases except for initial application of $MgCl_2$ salt at a rate of 2,420 gal/acre (0.50 gal/yd^2).

[3]Total cost = cost of initial application + cost of subsequent applications to maintain control during a 3 month season.

[4]Initial application cost for $MgCl_2$ salt is nearly twice that for subsequent applications, because the initial application rate is 0.5 gal/yd^2 and subsequent applications are 0.25 gal/yd^2.

dust control chemicals on two plant species commonly used to revegetate Minnesota taconite tailing basins. Tests were conducted in a laboratory growth chamber with perennial ryegrass and yellow sweet clover. Successful dust control chemicals and their application rates evaluated under contract J0218024 and tested in the laboratory were as follows:

Chemical	Application of chemical	
	lb/acre	gal/acre
Coherex resin.........	1,030	120
Lignin sulfonate......	2,360	240
Lime-neutralized lignin sulfonate.....	2,360	240
Nalco 656 latex.......	80	10
$MgCl_2$ salt (dry)......	13,310	1,210
$MgCl_2$ salt (wet)......	26,620	2,420

Table 9 contains a description of the chemicals and table 10 contains additional application data. Lime-neutralized lignin sulfonate was included in this evaluation as it was suggested by the manufacturer after completion of contract J0218024. It was not evaluated for dust suppression; however, except for a higher pH, its characteristics are reportedly almost identical to those of lignin sulfonate.

Four replicates of each seed species and chemical combination were tested in the laboratory, including control plantings without chemical treatment in tailing and a potting soil mix. Each replicate consisted of nine seeds in a 2.25-in-square plastic pot randomly placed within the growth chamber. The daily chamber cycle consisted of 12 h of light and 12 h of dark, with temperatures ranging from 65° to 80° F during the 24-h cycle. Moisture and fertilizer were added to all pots as necessary to promote germination and growth. Emergence and growth rates were recorded to evaluate the effects of chemical addition on the vegetation during the 2-week test period. Table 14 contains the summarized data.

The emergence or survival of ryegrass ranged from 0 to 100 pct. Both $MgCl_2$ salt treatment rates prevented ryegrass germination, probably because that grass species is susceptible to salt toxicity. The 83-pct germination with lignin sulfonate treatment reflects the survival of germinated seedlings (high of 86 pct) as some damping-off occurred with that treatment. Seedlings treated with Coherex, Nalco 656, and lime-neutralized lignin sulfonate exceeded the emergence achieved in either untreated tailing or potting soil, indicating some potential benefits of these chemicals.

Ryegrass growth rates ranged from 0.16 to 0.28 in/d after germination for the surviving vegetation. The high rate of 0.28 in/d reflects the ideal potting soil growth medium, and the low rate of 0.16 in/d reflects the probable impact of lignin sulfonate's low pH. Growth rates with the remaining chemical treatments slightly exceeded that with the tailing

TABLE 14. - Laboratory growth chamber results

Chemical treatment by soil type	Ryegrass		Sweet clover	
	Emergence, pct	Growth rate, in/d	Emergence, pct	Growth rate, in/d
Potting: None.........	86	0.28	54	0.10
Tailing:				
None.................	89	.19	61	.09
Lignin sulfonate[1]....	83	.16	17	.05
Lime-neutralized lignin sulfonate....	100	.21	58	.09
Nalco 656............	100	.19	64	.10
Coherex..............	94	.20		
$MgCl_2$ salt[2]..........	0	0	0	0

[1]Emergence shown is survival as damping-off occurred. See text.
[2]Zero emergence at both addition rates.

material only, indicating little benefit from these treatments.

The legume sweet clover emergence ranged up to 64 pct. The general reaction of the legume to the chemical treatments was the same as for the ryegrass. As with the grass, no emergence occurred with the $MgCl_2$ salt additions. Nalco and lime-neutralized lignin sulfonate treatments were again at or near the top of the emergence results, followed closely by tailing without chemical treatment and potting soil. The Coherex treatment was lower in emergence at 44 pct, but lignin-sulfonate-treated legumes suffered severe damping off, and survival amounted to only 17 pct (down from an actual emergence high of 42 pct).

Growth since planting was almost identical for all chemical treatments of the legume except lignin sulfonate, which resulted in half the rate for other treatments.

Field Study

Laboratory results were tested in a cursory field study at the National Steel tailing basin near Keewatin, MN. Ten 1.0-m^2 plots were prepared for testing with the successful chemicals from the laboratory testwork and a standard revegetation seed mix used by the M. A. Hanna Co. (manager of National Steel). A typical fertilizer rate of 580 lb/acre of 12-24-3 was used on half the plots. The seed mix consisted of an annual nurse crop (rye grain), grasses (reed canary and red top), and legumes (alsike clover and sweet clover). Test variations are given in table 15, along with measured results.

Vegetation response was evaluated about 6 weeks after the June 1983 planting, after an initial 4 weeks of nearly ideal growing weather followed by 2 weeks of drought. Unfortunately, a rather severe rainstorm occurred at the end of the 4-week period, washing away all surface effects of the chemical treatments. What remained was vegetation that had germinated and grown sufficiently to withstand the water erosion caused by the storm. At the 6-week evaluation point, vegetation response was counted by dividing each square meter plot into 100 equal units and counting the plants in 10 randomly chosen units (10 pct of the total plot). Results are given in table 15.

TABLE 15. - Field test plot results[1]

Chemical treatment	Fertilized	Vegetation response, plants/m^2
Lime-neutralized lignin sulfonate:		
Plot 2.............	No	60
Plot 10............	Yes	880
Lignin sulfonate:		
Plot 3.............	No	50
Plot 6.............	Yes	140
Coherex:		
Plot 9.............	No	20
Plot 4.............	Yes	290
Nalco 656:		
Plot 5.............	No	20
Plot 8.............	Yes	60
None:		
Plot 7.............	No	170
Plot 1.............	Yes	50

[1]Results 6 weeks after planting.
[2]Seed mix consisted of rye grain--30 lb/acre, reed canary--10 lb/acre, alsike clover--6 lb/acre, red top--3 lb/acre, sweet clover--6 lb/acre, total of 55 lb/acre.

Generally, only plots with fertilizer addition resulted in vigorous growth, and the majority of the surviving vegetation was red top grass. Results of the field tests were more dramatic than those in the laboratory test, with the vegetation response to the lime-neutralized lignin sulfonate chemical treatment (with fertilizer) far exceeding that from any other treatment (table 15). Except for the control plot with no chemical treatment, fertilizer addition increased all vegetation response by factors ranging from 3 (Nalco 656 and lignin sulfonate) to 15 (Coherex and lime-neutralized lignin sulfonate) over response in the nonfertilized plots.

Visual observations 3 months after planting generally confirmed the above vegetative response trends. The plots with fertilizer had more complete coverage, with the lignin sulfonate treatments resulting in 60 to 75 pct cover, and the

Coherex and Nalco 656 treatments resulting in 20 to 30 pct cover. It was impossible to count individual plants at this point, and the percent cover was estimated from photographs of each plot. All other treatments resulted in 0 to 10 pct cover.

Because no replicates were incorporated in the field study, results are to be taken as directorial only. Complete statistical testing would be necessary to verify the results indicated.

SUMMARY AND RESULTS

HAULAGE ROAD DUST CONTROL

Dust measurements taken on a haulage road at a midwestern sand and gravel operation where various chemical dust suppressants were applied showed that $MgCl_2$ salt was the most effective dust suppressant under the conditions encountered, with an average control efficiency of 98 pct during the month following application. Dust plumes from traffic were either eliminated or greatly reduced on the salt-treated section. The area remained damp during the test period, and the $MgCl_2$ salt also dampened additional material falling from the trucks onto the road surface, preventing dust generation from that source.

The petroleum derivative formed a crust on the road surface but became susceptible to dust generation from additional material falling onto the road surface. The control efficiency ranged from 49 to 84 pct. Determining the efficiency reduction over a longer period would have been desirable under this project but was not possible. The testing of these two chemicals had to be discontinued when the pit operation was closed for the winter.

Analysis of the wetting agent testing data failed to indicate any significant difference between the two types of control. Under these conditions, it would be doubtful that use of this chemical would reduce the number of waterings required per day. One question that remains is that of change over long-term use of the product through conditioning of the road surface. The limited scope of this research did not permit this type of testing.

A Reddaway-type fender, designed to more completely enclose the wheels on a haul truck and control dust generation, was constructed and installed on a 5-yd^3-capacity dump truck. Tests showed no improvement in dust control when using the fender. The dust plume formed an acute angle with the road surface toward the rear of the tire, which permitted dust to escape through the 4- to 6-in space below the base of the fender. Lowering the fender is impractical because of irregular road surfaces. The use of standard mudflaps during the fender testing resulted in a 38 pct reduction in dust emissions compared with tests using no wheel enclosure. These results should be considered preliminary. A thorough study of flap design, truck type, and speed would have to be performed if this were to be considered as a dust reduction technique. However, a 38 pct reduction in haulage road dust emissions may not be satisfactory. This is much less than the 99-pct level of control offered by $MgCl_2$ salt in this project and also less than that of the petroleum derivative.

TAILING BASIN DUST CONTROL

The Bureau awarded a contract to study the effectiveness of chemical stabilization at tailing disposal areas. Varying strengths of petroleum resin (Coherex), lignin sulfonate (Flambinder), and latex (Nalco 655 and 656) dust suppressants and two methods of $MgCl_2$ salt application were field-tested on a northern Minnesota taconite tailing basin. Two months after application the average control efficiencies were as follows: $MgCl_2$ salt applied to wet tailing material--82 pct; Nalco 655--69 pct; Nalco 656--67 pct; $MgCl_2$ on dry tailing material--65 pct; lignin sulfonate (4:1 dilution ratio)--43 pct. After 4 months the control percentages ranged from 66 to 31 pct, with no significant change in order among the chemicals tested. The major conclusions reached under this contract were--

1. Tailing basin dust control is being addressed by more companies than in the past.

2. Very few mining operations have established tailing basin dust control programs, many operators are experimenting with various dust control chemicals to determine which are best suited to their type of operation, and many of these experimental programs are inconclusive because the operator is usually unable to quantify the effects of the stabilizers over time.

3. Many types of chemicals are available, but only a few have widespread acceptance as being effective, such as petroleum resins, lignin sulfonates, and salts.

4. Specialized equipment necessary to apply the chemical stabilizers onto the tailing material was not available until recently.

5. Criteria for selecting a chemical stabilizer and implementing a successful dust control program are related to--

   a. Characteristics of the tailing surface.
   b. Meteorological conditions expected during the lifetime of the applied product.
   c. Control efficiency desired over time.
   d. Problems with the product affecting the mineral recovery process.
   e. Special product usage requirements.
   f. Overall product cost effectiveness.

Bureau research was conducted to evaluate the effects of dust control chemical addition on vegetation establishment on a Minnesota taconite tailing material. The theory being tested was that initial dust control could be achieved by chemical treatment while permanent vegetative cover was being established. The chemical treatment must not hinder seed germination and survival and must protect tender seedlings until they are able to withstand wind and water erosion of the tailing.

Laboratory growth chamber results showed that $MgCl_2$ salt addition prevented vegetation germination, while lignin sulfonate reduced both emergence and growth rate of ryegrass and sweet clover. Nalco 656, Coherex, and lime-neutralized lignin sulfonate chemical additions had minor positive effects on the response of both grass and legume species.

The field study, although not statistically based, indicated that the lime-neutralized lignin sulfonate treatment with fertilizer improved vegetation survival and growth. Coherex and Nalco 656 also improved the vegetative response on fertilized test plots, but to a lesser extent.

REFERENCES

1. Evans, J. S., and D. W. Cooper. An Inventory of Particulate Emissions From Open Sources. J. Air Pollut. Control Assoc., v. 30, No. 12, Dec. 1980, pp. 1298-1302.

2. Axetell, K. Survey of Fugitive Dust From Coal Mines. U.S. EPA, Rep. EPA-0981/1-78-003, 1978, 114 pp.

3. Sittig, M. Particulates and Fine Dust Removal: Processes and Equipment. Noyes Data Corp., Park Ridge, NJ, 1977, 604 pp.

4. Rosbury, K. D., and R. A. Zimmer. Cost-Effectiveness of Dust Controls Used in Unpaved Haul Roads (contract J0218021, PEDCo Environmental, Inc.). Volume I: Results, Analysis, and Conclusions. BuMines OFR 106(1)-85, 1983, 134 pp.; NTIS PB 86-115201.

5. Bohn, R. R., and J. D. Johnson. Dust Control on Active Tailings Ponds (contract J0218024, Environmental Services and Technology). BuMines OFR 112-83, 1983, 124 pp.; NTIS PB 83-216382.

6. Spraying Systems Co. (Wheaton, IL). Agricultural Spray Nozzles and Accessories. Spray Manual Catalog 37, undated, p. 15.

7. Williams, K. L., and R. J. Timko. Performance Evaluation of a Real-Time Aerosol Monitor. BuMines IC 8968, 1984, 20 pp.

8. Lilienfeld, P. Improved Light Scattering Dust Monitor (contract H0377092, GCA Corp.). BuMines OFR 90-79, 1979, 44 pp.; NTIS PB 299-938.

9. Bohn, R., T. Cuscino, D. Lane, F. Pendleton, and R. Hackney. Dust Control for Haulage Roads (contract J0285015, Midwest Research Inst.). BuMines OFR 130-81, 146 pp.; NTIS PB 82-116666.

10. St. Paul Dispatch. Weather Section. Oct. 15, 19, and 27, 1982.

11. Weir, D. H., J. F. Strange, and R. K. Hoffley. Reduction of Adverse Aerodynamic Effects on Large Trucks. Volume 1. Technical Report (U.S. DOT contract DOT-FH-11-9165, Systems Technology, Inc.). Fed. Highway Admin. (Dep. Transportation), FWHA-RD-79-84, Sept. 1978, 378 pp.

12. Buckley, B. S., and E. V. Laitone. Airflow Beneath an Automobile. SAE preprint 741028, 1974, 7 pp.

13. Marks, C. H., and F. T. Buckley, Jr. A Wind-Tunnel Study of the Effect of Turning Vanes on the Aerodynamic Drag of Tractor-Trailer Trucks. ASME preprint 77-WA/FE-15, 1977, 9 pp.

14. Buckley, F. T., Jr., and C. H. Marks. A Wind-Tunnel Study of the Effect of Gap Flow and Gap Seals on the Aerodynamic Drag of Tractor-Trailer Trucks. ASME preprint 77-WA/FE-23, 1977, 9 pp.

15. Ogden (UT) Standard-Examiner. Great Salt Lake Mineral Company Comes of Age. Aug. 9, 1981, pp. 2E-3E.

16. Hogdin, C. R. Logarithmic Wind Profile Parameters Applied to Air Quality Assessment Studies. Paper in Second Joint Conference on Applications of Air Pollution Meteorology and Second Conference on Industrial Meteorology (Air Pollution Control Association and American Meteorological Society, New Orleans, LA, Mar. 24-28, 1980). Am. Meteorol. Soc., Boston, MA, 1980, pp. 770-776.

17. Federal Register. U.S. Environmental Protection Agency. Standards of Performance for New Stationary Sources, Revisions to Reference Method 1-8. V. 42, No. 160, Aug. 1977, pp. 41754-41789.

18. Stevens, R. K., and T. G. Dzubay. Dichotomous Sampler--A Practical Approach to Aerosol Fractionation and Collection. U.S. EPA, Rep. EPA/600 12-78-112, June 1978, 31 pp.; NTIS PB 284-091.

APPENDIX.--INDIVIDUAL HAULAGE ROAD DUST EMISSION MEASUREMENTS

TABLE A-1. - Individual dust emission measurements of areas treated with petroleum derivative and $MgCl_2$ salt and an untreated area[1]

Dust suppressant chemical and test area (fig. 2)	Time	Reading, mg/m^3
TEST 1, OCTOBER 14, 1982		
$MgCl_2$ salt, area 3.......	1313	0.32
	1316	.03
	1321	.03
	1326	.15
	1330	1.00
	1333	B
	1336	.04
	1341	.06
Av reading, area 3.......		.21
Petroleum derivative, area 4..................	1345	1.86
	1348	.34
	1352	.84
	1358	.55
	1402	.88
	1405	.16
	1409	.67
	1418	1.02
Av reading, area 4.......		.79
Untreated, area 5........	1422	1.62
	1426	.77
	1430	1.55
	1432	1.57
	1436	1.57
	1442	1.72
	1449	1.64
	1451	1.24
	1452	2.00
Av reading, area 5.......		1.52
TEST 2, OCTOBER 18, 1982		
$MgCl_2$ salt, area 3.......	1032	B
	1035	B
	1036	B
	1040	0.03
	1049	.04
	1052	.03
	1058	B
	1059	.03
	1106	B
	1334	.04
	1336	.03
TEST 2, OCTOBER 18, 1982--Con.		
	1342	0.04
	1345	.04
	1356	.05
	1359	.04
$MgCl_2$ salt, area 3--Con.	1401	.03
	1401	.05
	1406	.04
	1412	B
	1417	B
Av reading, area 3.......		.03
Petroleum derivative, area 4..................	1117	.09
	1119	.23
	1124	.18
	1127	.12
	1137	.14
	1142	.10
	1143	.23
	1144	.06
	1153	.28
	1342	.37
	1345	.80
	1351	1.24
	1356	.25
Av reading, area 4.......		.31
Untreated, area 5........	1306	.71
	1310	1.75
	1313	1.00
	1317	1.65
	1326	1.45
	1329	1.18
	1334	1.29
Av reading, area 5.......		1.29
TEST 3, OCTOBER 26, 1982		
$MgCl_2$ salt, area 3.......	1409	0.32
	1414	.14
	1418	.22
	1421	.24
	1423	.18
	1427	.14
	1432	.28
	1435	.08
Av reading, area 3.......		.20

TABLE A-1. - Individual dust emission measurements of areas treated with petroleum derivative and $MgCl_2$ salt and an untreated area[1]--Continued

Dust suppressant chemical and test area (fig. 2)	Time	Reading, mg/m^3	Dust suppressant chemical and test area (fig. 2)	Time	Reading, mg/m^3
TEST 3, OCTOBER 26, 1983--Con.			TEST 3, OCTOBER 26, 1983--Con.		
Petroleum derivative, area 4.................	1329	5.8	Untreated, area 5........	1246	5.9
	1331	.9		1249	14.1
	1338	1.50		1253	18.8
	1340	1.70		1258	6.2
	1342	1.93		1302	19.2
	1344	1.67		1306	17.7
	1350	1.90		1312	12.6
	1353	1.81		1315	8.6
	2356	1.80		1319	9.8
	1359	1.58	Av reading, area 5.......		12.54
	1406	1.83			
Av reading, area 4.......		2.04			

B Background level.

[1]Test conditions were as follows:

	Test 1	Test 2	Test 3
Background dust conc.........................mg/m^3..	0.01-0.02	0.01-0.02	0.02-0.05
Wind velocity................................mi/h..	5-10	5-10	5-10
Wind direction....................................	SW	S	SSE

TABLE A-2. - Individual dust emission measurements of a section treated with a resin-type dust suppressant and an untreated section,[1] milligrams per cubic meter

Time	Untreated[2] (area 4)	Resin treated[2] (area 3)
TEST 4, JULY 6, 1983		
1146	NAp	9.3
1157	NAp	6.5
1204	NAp	.67
1216	NAp	13.6
1220	NAp	5.9
1228	NAp	12.9
1241	0.5	NAp
1247	2.7	NAp
1253	2.0	NAp
1259	4.0	NAp
1306	2.4	NAp
1312	5.8	NAp
Av	2.9	9.2
TEST 5, JULY 12, 1983		
1152	3.0	NAp
1152	1.7	NAp
1156	4.2	NAp
1156	5.4	NAp
1202	6.2	NAp
1202	7.7	NAp
1207	9.4	NAp
1207	9.0	NAp
1213	12.5	NAp
1213	13.9	NAp
1218	10.0	NAp
1218	9.6	NAp
1231	NAp	11.1
1231	NAp	18.1
1234	NAp	12.5
1234	NAp	15.1
1239	NAp	12.1
1239	NAp	14.8
1243	NAp	8.0
1243	NAp	10.0
1247	NAp	12.3
1247	NAp	18.1
1250	NAp	10.5
1250	NAp	18.8
1253	NAp	14.4
1253	NAp	[3]20+
Av	7.7	14.0

Time	Untreated[2] (area 4)	Resin treated[2] (area 3)
TEST 6, JULY 14, 1983		
1037	1.6	1.5
1039	.4	.7
1047	.1	2.4
1051	.6	2.2
1055	.1	.8
1059	.9	2.5
1105	.9	5.2
1105	.7	.5
1112	1.2	1.0
1113	.4	1.8
1118	.9	1.6
1118	.8	1.5
1127	.9	5.0
1129	1.2	5.6
1129	.8	12.3
1132	9.6	8.1
1132	4.5	5.2
1157	3.8	1.2
1202	1.2	5.6
1206	2.4	8.6
1210	1.9	13.3
1214	5.6	4.8
1220	1.6	10.8
1124	1.6	5.6
1228	7.2	5.2
1231	4.0	10.2
1236	5.6	14.4
1240	3.6	8.4
1244	4.0	11.3
1247	2.5	7.2
1251	6.6	2.5
1259	5.6	16.8
1312	7.2	4.8
Av	2.7	5.7

NAp Not applicable (sample not taken).
[1]Test conditions were as follows:

	Test 4	Test 5	Test 6
Background dust conc....mg/m^3..	0.2	0.2	0.01-0.02
Wind velocity....mi/h..	5-10	5-10	5-10
Wind direction....	S	SSE	S

[2]See figure 2. [3]Considered as 20 mg/m^3 for computing average.

TABLE A-3. - Individual dust emission measurements of areas treated with wetting agent solution and water[1]

Time	Wetting agent and water (area 4)[2]		Water only (area 5)[2]	
	Time since application, min	Reading, mg/m^3	Time since application, min	Reading, mg/m^3
TEST 7, JULY 21, 1983				
1048	103	0.4	83	0.8
1052	107	.3	87	2.1
1057	112	1.0	92	2.1
1059	114	1.7	94	.6
1102	117	1.0	97	.6
1106	121	1.2	101	.6
1111	126	2.1	106	1.2
1115	130	1.9	110	1.7
1119	134	3.4	114	.6
1123	138	2.5	118	1.0
1130	145	2.6	125	3.5
1201	176	1.6	156	2.0
1206	181	2.3	161	4.8
1211	186	2.0	166	3.5
1214	189	1.0	169	2.4
1218	193	3.2	173	3.2
1223	198	6.0	178	5.9
1228	203	5.0	183	2.8
1231	206	3.0	186	4.0
1235	210	3.6	190	1.8
1239	214	1.9	194	5.8
1241	216	5.2	196	5.5
1246	221	3.4	201	6.1
1250	225	6.1	205	4.3
1253	228	3.9	208	7.8
1259	234	9.6	214	5.9
1300	235	6.0	215	3.9
1304	239	5.3	219	4.7
2309	244	4.4	224	3.7
1310	245	7.3	225	2.5
TEST 8, JULY 22, 1983				
955	75	1.3	55	0.4
1002	82	2.3	62	.4
1014	94	1.9	74	.8
1027	107	1.2	87	1.6
1034	114	1.7	94	1.3
1041	121	3.4	101	1.8
1052	132	2.6	112	1.0
1055	135	3.4	115	1.7
1105	145	4.9	125	.8
1115	155	1.9	135	1.1
1123	163	4.4	143	2.1
1130	170	4.3	150	3.2
1154	194	2.9	174	3.8
1207	207	7.1	187	3.8
1211	211	8.8	191	5.4
1220	220	13.3	200	8.3
1224	224	9.3	204	2.8
1225	225	5.6	205	4.1

TABLE A-3. - Individual dust emission measurements of areas treated with wetting agent solution and water[1]--Continued

Time	Wetting agent and water (area 5)[2]		Water only (area 4)[2]	
	Time since application, min	Reading, mg/m³	Time since application, min	Reading, mg/m³
TEST 9, JULY 27, 1983				
1050....................	90	1.2	60	1.4
1053....................	93	1.7	63	4.4
1100....................	100	1.7	70	1.4
1104....................	104	2.8	74	3.3
1109....................	109	1.7	79	3.4
1113....................	113	2.8	83	3.3
1121....................	121	9.4	91	5.4
1123....................	123	4.3	93	3.0
1128....................	128	5.2	98	1.2
1200....................	160	3.4	130	7.1
1204....................	164	5.5	134	2.9
TEST 10, AUGUST 9, 1983				
1035....................	35	0.0	80	2.0
1045....................	45	.1	90	4.7
1048....................	48	.4	93	2.4
1058....................	58	.8	103	4.3
1101....................	61	1.2	106	2.6
1111....................	71	.0	116	3.0
1119....................	79	1.4	124	5.6
1123....................	83	1.8	128	([3])
1131....................	91	([3])	136	8.8
1204....................	124	3.3	169	5.9
1222....................	142	8.9	187	13.0
1226....................	146	7.2	191	9.6
1230....................	150	7.1	195	5.0
1233....................	153	5.1	198	9.1
1237....................	157	2.5	202	5.0
1242....................	162	10.1	207	4.5
1250....................	170	9.2	215	3.9
1256....................	176	4.9	221	6.1

[1]Test conditions were as follows:

	Test 7	Test 8	Test 9	Test 10
Background dust conc........................mg/m³..	0.01-0.02	0.1	0.02	0.02
Wind velocity................................mi/h..	5-10	5-10	5-10	5-10
Wind direction....................................	SSW	NW	SE	S

[2]See figure 2. [3]Measurement not taken.

TABLE A-4. - Individual dust emission measurements from a 5-yd^3 dump truck fitted with various fender and mudflap configurations and mine haulage vehicles[1]

Measurement	Dust level, mg/m^3	Measurement	Dust level, mg/m^3
5-yd^3 dump truck:		5-yd^3 dump truck--Con.	
No special equipment:		Extended Reddaway fender:	
1	0.83	1	1.45
2	1.41	2	.60
3	.77	3	.90
4	.90	4	.94
5	1.00	5	1.35
6	1.34	Av	1.05
7	1.07	Std dev	.35
8	1.75	Mine haulage vehicle:	
Av	1.13	1	.65
Std dev	.34	2	.88
Standard mudflaps:		3	.74
1	.71	4	.97
2	.76	5	1.31
3	.70	6	1.30
4	.68	7	1.00
5	.67	8	1.82
Av	.70	9	1.61
Std dev	.04	10	.55
Reddaway fender:		11	1.13
1	.87	12	.18
2	.83	13	1.08
3	.98	14	.35
4	.65	15	.77
5	1.45	16	.46
6	1.52	17	1.37
7	.86	18	1.15
Av	1.02	Av	.96
Std dev	.33	Std dev	.44

[1]Date and test conditions:

Date	Sept. 22, 1982
Background dust loading mg/m^3	0.02
Wind velocity mi/h	5
Wind direction	SSW
Chemical treatment of road surface	None
Speed of 5-yd^3 dump truck mi/h	30

U.S. GOVERNMENT PRINTING OFFICE: 1987 - 605-017/60026 176

INT.-BU.OF MINES,PGH.,PA. 28407